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Welcome to Baltimore!

It is with great pleasure that I personally welcome you to the 2014 AMSAT Annual Meeting and Space Symposium. This is the 32nd Space Symposium, reflecting a long tradition (started in the early 1980's) to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas. AMSAT is proud of the technical content of the papers presented over the years reflecting the inventiveness of our volunteers and the significant contribution of presenters to "advancing the radio art."

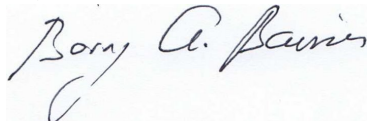
Holding our Symposium at BWI this year is certainly fitting as 2014 marks the 45th Anniversary of AMSAT which was incorporated in Washington, DC in 1969. As we reflect upon AMSAT's significant achievements over the years, we recognize that the environment in which AMSAT exists today has changed significantly with respect to how AMSAT can continue to develop and build satellites and find launches for amateur radio spacecraft, as well as secure funding necessary to fly our satellites. Consequently, AMSAT is pursuing a strategy of 1) building affordable satellites that can be built and flown with appropriate fundraising, 2) partner with universities and other sources of scientific payloads which provides the funding justification for launches provided by NASA or other sources for AMSAT-developed spacecraft, and 3) when appropriate work with other launch integration organizations in order to mitigate launch uncertainties where AMSAT pays for the launch. We're excited that we expect to have Fox-1A and Fox-1C fly in 3rd quarter 2015 under two different launch arrangements; in addition, Fox-1B is accepted under the NASA ELaNa program but not yet assigned to a launch opportunity. Meanwhile, we continue to look for a launch opportunity for Fox-1D.

As the Fox-1 Program draws to a conclusion in 2015, we are initiating the process of defining our next program which to date has been called "Fox-2." The 32nd Space Symposium offers an opportunity to begin the conversation to define the operational goals and the technical expectations of this new program.

Once again, the relative importance of the Proceedings is reflected in the placement of our technical development work. While the transition of amateur radio satellites from the US Munitions List managed by International Traffic in Arms Regulations (ITAR) to the Export Administration Regulations (EAR) takes place this November, we recognize that our satellite programs are still under ITAR as this Symposium takes place and we must comply with current provisions. In order for AMSAT to continue to openly present technical information concerning our satellite designs, we must first place this information into the public domain under current ITAR and future EAR stipulations. The only approach that the US Government currently recognizes for placement of technical materials subject to ITAR in the public domain is by physically publishing the material and then making that publication available to the public at large. Thus, we continue to place updated information regarding our Fox-1 program in this year's Proceedings so that we may publicly discuss our project in greater detail and not be in violation of US law.

After forty-five years, we continue to develop remarkable satellites with educational outreach that now serves as the basis for future launch opportunities. Your support will help to ensure a bright future.

73,



Barry A. Baines, WD4ASW
President



Anthony “Tony” J. Monteiro, AA2TX, AMSAT Vice President of Engineering and member of the Board of Directors, died on March 26, 2014 while hospitalized for cancer. He was 55 years old. Tony is survived by his wife Mary Lou and daughter Veronica.

Tony was first licensed as a Novice in 1973 and subsequently held an Extra Class Amateur Radio License. An avid operator, he described his first contact in an AMSAT BoD Candidate’s Statement in 2011: “I earned my novice ticket in 1973 and made my first ham radio contact with a transmitter made from parts out of an old TV set. A Heathkit HR-10B receiver and a 65-foot piece of wire strung out of a window for an antenna made up the rest of my station, which was pretty modest even by 1973 standards! Even so, I will never forget the thrill of my very first contact.”

His interest in amateur radio and electronics led him to earn a BS in Electrical Engineering from Drexel University and a MS in Computer Science from Stanford University. His professional career started at Bell Laboratories in New Jersey developing network management systems and then consumer products. After working at several startup companies, Tony landed at Cisco Systems where he managed the development of ADSL, voice over packet, and content networking products. He retired from industry in 2002 and focused his efforts working on satellite projects.

Tony joined AMSAT in 1994 and started working the satellites. He earned ARRL VHF/UHF Century Club-Satellite #58 and worked 49 states (only Hawaii was not logged) as well. Tony worked a number of stations while he commuted along the I-495 corridor outside Boston. Many will remember working him through AO-40 as he utilized his “cardboard box horn antenna.” Tony led a workshop at the 2003 AMSAT Space Symposium where students built similar antennas, demonstrating the ease in which one could build a 2.4 GHz S-band antenna to receive the AO-40 downlink.

Additional technical contributions to the amateur satellite community that Tony made included “InstantTune Automatic Radio Tuning” software, “A Simple Desense Filter for Echo”, and several extremely low cost projects such as “A \$5 Mode V/S Adapter using a Sub-Harmonic Mixer”. AMSAT-UK currently offers a 70 CM Parasitic Lindenblad antenna based upon his design.

Tony also played a significant role in space-based hardware development. He collaborated on the NO-60 satellite. As AMSAT’s Vice President of Engineering, he served as the software designer for the SDX (Software Defined Transponder) on ARISSat-1/Kedr that was deployed from the International Space Station by Russian Cosmonauts during a space walk in August 2011. Tony led the Fox-1 Engineering Team from inception in 2009 and led AMSAT’s efforts to apply for acceptance of Fox-1 in the NASA Educational Launch of NanoSat (ELaNA) in 2011 and Fox-1B in 2012. He established relationships with several universities to secure scientific payloads for Fox-1 and Fox-1B, including student experiments.

A strong proponent of student involvement in satellite projects, Tony served as coordinator of AMSAT Engineering relationships with SUNY-Binghamton, Penn State-Erie, Virginia Tech, and Rochester Institute of Technology where students developed new technologies to be applied in future AMSAT spacecraft as “Capstone” projects. These projects, such as the development of storage capacitors to replace batteries developed by SUNY-Binghamton, provided student experiences that will ultimately be flown in space. The AMSAT JOURNAL in recent years featured several articles concerning these projects.

Tony was elected to the AMSAT Board of Directors in 2011 following service for one year as a BoD alternate. His wise counsel and focus on finding ways to make it affordable for AMSAT to fly amateur radio systems in space resulted in several innovative approaches. It was Tony that convinced the NASA ELaNA program to modify their qualification criteria to add “not for profits” to those that could apply for launch grants. It was Tony that met with universities that were looking for ways to fly their payloads but didn’t have the experience to build satellites, encouraging collaboration that would benefit both AMSAT and the university.

Tony’s approach to participation in the AMSAT Leadership Team reflected his approach to life. Whenever he had a thought to share with the entire AMSAT Board of Directors and/or Senior Officers via e-mail, he always started with “Dear Friends”. As AMSAT VP-Operations Drew Glasbrenner, KO4MA noted, “I always admired how he reminded me we were all friends despite whatever argument was raging.”

AMSAT Engineering 2014 – Introducing Virtual Teamwork

Fox-1 is not only new territory for AMSAT in that it is our first CubeSat. The engineering process in developing and building Fox-1 is also breaking new ground.

While taking advantage of common file repositories with versioning and online meetings helps bring volunteers from across the United States together to work on Fox-1, other new possibilities taking advantage of the internet have been introduced in the testing of Fox-1.

In the past, as you may know from our history, satellites have been built in facilities ranging from a team member's garage or basement to clean rooms that AMSAT owned. With the decrease in size of the CubeSat as compared to our recent endeavors, the ability to test the whole satellite on a tabletop in the comfort of one's own ham shack is now possible. Imagine having all of this testing going on *inside* the house, with XYL consent!

The ability to do the work in my shack/office offers the possibility of having convenient use of multiple PCs, telephones, online conferencing, and file sharing. My shack satellite radios and FUNcube Dongle Pro Plus are at hand with various antennas for testing the transponder, monitoring the downlink, and capturing SDR recordings of the downlink for software analysis and development. These SDR recordings give the software developers full spectrum recordings of the received signal for use in creating and fine tuning the software both on the satellite IHU and in the ground station software that will be available to all radio amateurs when the satellites are launched.

In an effort to maximize the efficient use of resources and money in getting Fox-1 and her sisters into orbit, we have introduced the use of some modern conveniences that allow an entire roomful of engineers to be present for the testing without traveling and staying away from home. This allows the team to be at their work area or PC as well, so that they can work on solutions to problems encountered in testing with the comfort and speed of their own equipment. It also saves thousands of dollars on travel and lodging.

The gatherings are based on AMSAT's GoToMeeting account, where the team members can come and go to an ongoing meeting that is available whenever the testing is underway. They may be actively participating, or just listening in to the testing that day. The Board of Directors and Senior Officers can drop in to keep up on the progress. The ability to share screens for reviewing documents and working on solutions expedites the process of reviewing requirements and changes.

But the addition of two technologies, one a common amateur radio application and the other a donation by a local ham, have added a level of convenience not used before.

Echolink is the application commonly used by hams for remote IP access to repeaters throughout the world and for conferencing. AMSAT has an Echolink conference that is opened up for events such as the annual meeting at the Symposium. Echolink allows an amateur radio operator to set up a Link station, which is in effect a remote control of their transceiver.

We have put that Link ability to use for our testing of Fox-1 in setting up an Echolink Link "N0JY-L" at my QTH, which gives the Fox Team members the ability to listen to and even talk through the Fox-1 transponder through my Yaesu FT-817 while the testing is underway.

The other convenience is in the form of a Sony IPELA SNC-RZ25N IP camera with remote control pan, tilt, and zoom capability. The camera, provided by Bob Fitzpatrick KB5SQG, has excellent imaging and gives the engineers the opportunity to peek over the shoulder of the tester to watch what is going on so they can provide input and feedback to performing tests as well as making observations.

With pre-set positions they easily zoom in on the satellite, the oscilloscope, the DVM, the thermometer, the frequency counter, the bench power supply, and even my laptop screen. Full control lets them see anything in the shack.

The result is marvelous. I can be positioning probes on test points in the satellite which requires me to use my magnifying goggles, and another team member can read the observations from the DVM without me having to take my sight off the probes or remove my goggles. Checking configurations and verifying readings for each step of the testing is possible. Software loads and debugging can be seen on the laptop screen. Telemetry readings from the IHU as viewed on my laptop can be viewed and verified as if the software engineer were at the keyboard.

Team members can also capture images from the camera for analysis or viewing while the camera is later positioned for other activities.

In the first week of engineering unit testing these tools were instrumental in conducting the tests quickly and efficiently and in analyzing results and problems found in hardware and software with immediate visual ability to view hardware and listen to downlink signals. We were able to step through the testing documents together, agreeing on the proper steps to be taken. The team was able to detect, analyze, and quickly make changes to software as well as plan hardware changes that took place when the satellite went "back to the shop" for a week of tweaks on July 5.

The Fox-1 Team members agree that the new use of these tools has given us the opportunity to test in a shared environment that is almost as good as being there. In fact, it may have advantages in that having four or five people around the table in the shack would be quite a crowding issue!

We will continue the use of these techniques throughout the Fox-1 Program. These images show some of our past satellites, and demonstrate the views of the camera to give you an idea of how the team can share in the action.

Image A – AO-51 testing

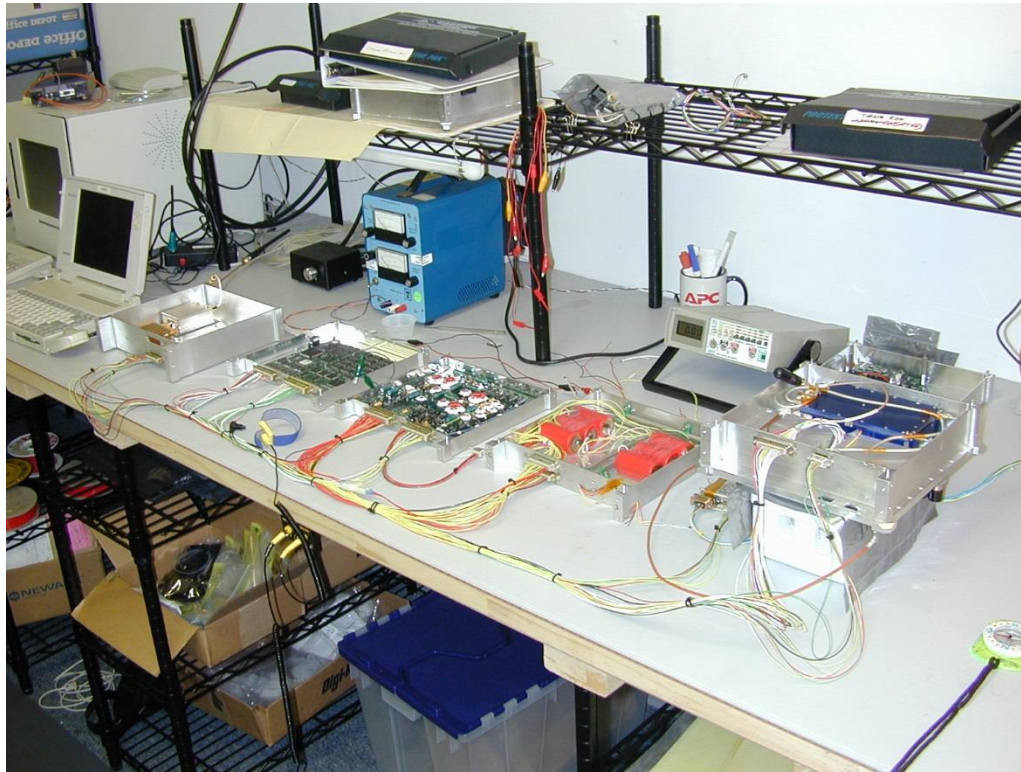


Image B – AO-51 testing



Image C – Fox-1 Engineering Unit under test in the N0JY shack

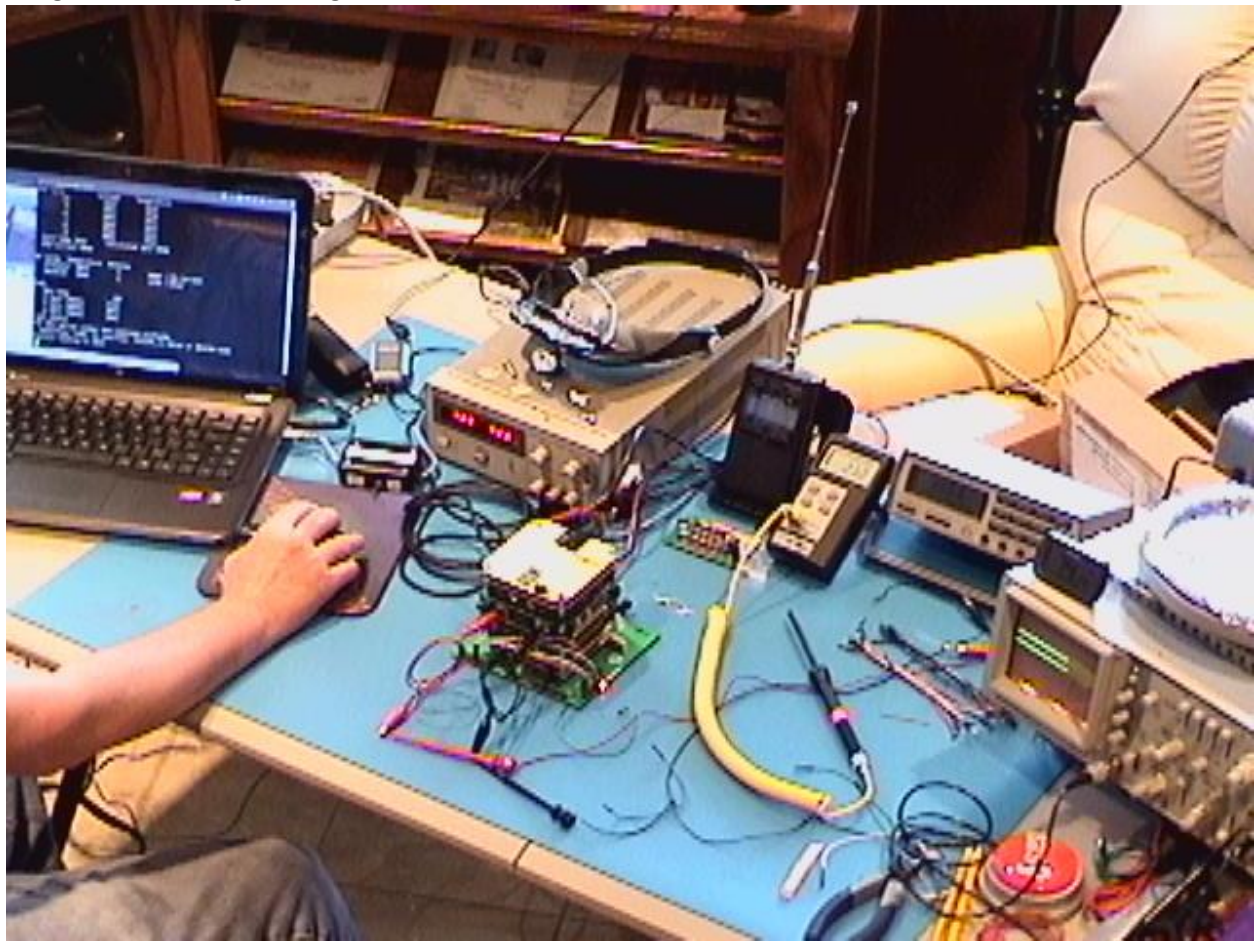


Image D – internet access to the Fox-1 Cam

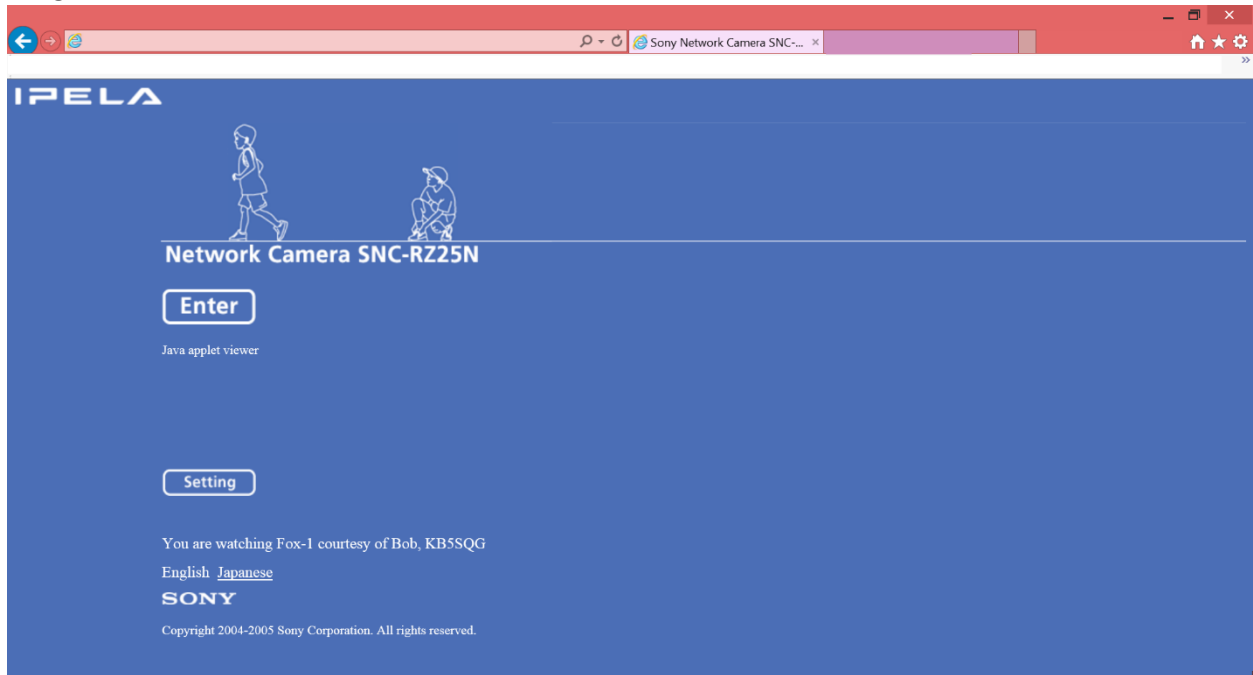


Image E – test pattern view “parked” position of the camera when not in use

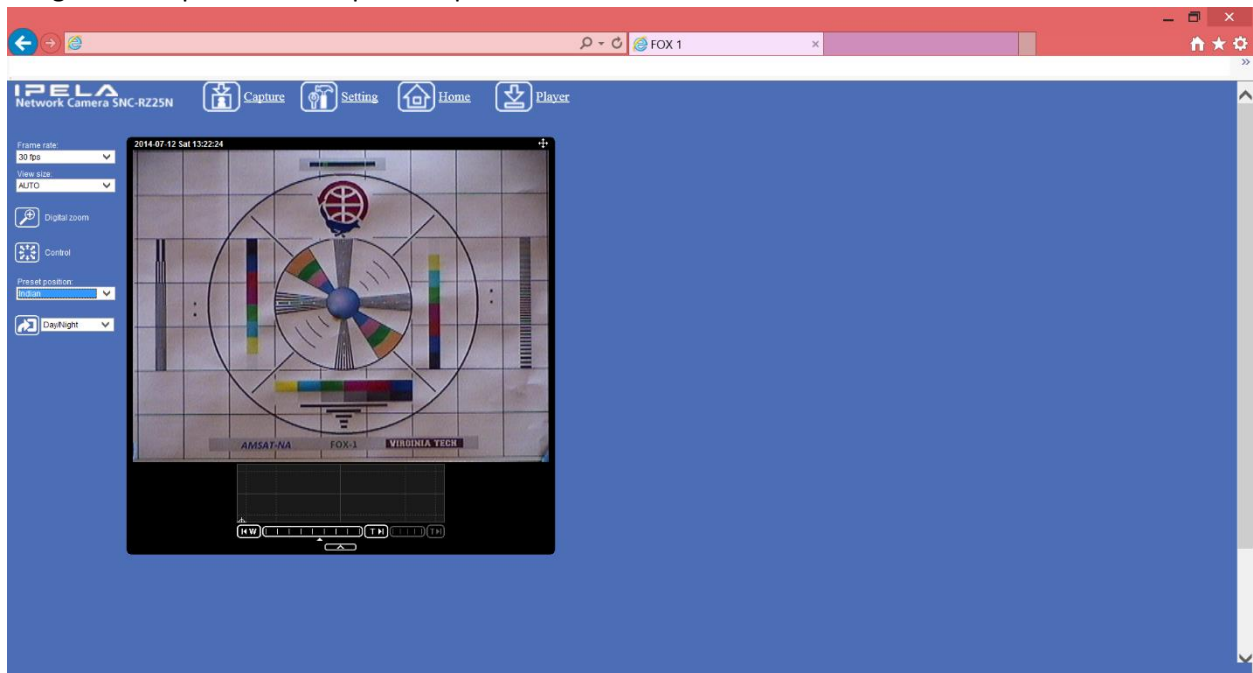


Image F – the Fox-1 Cam view of the DVM during a measurement of the battery voltage

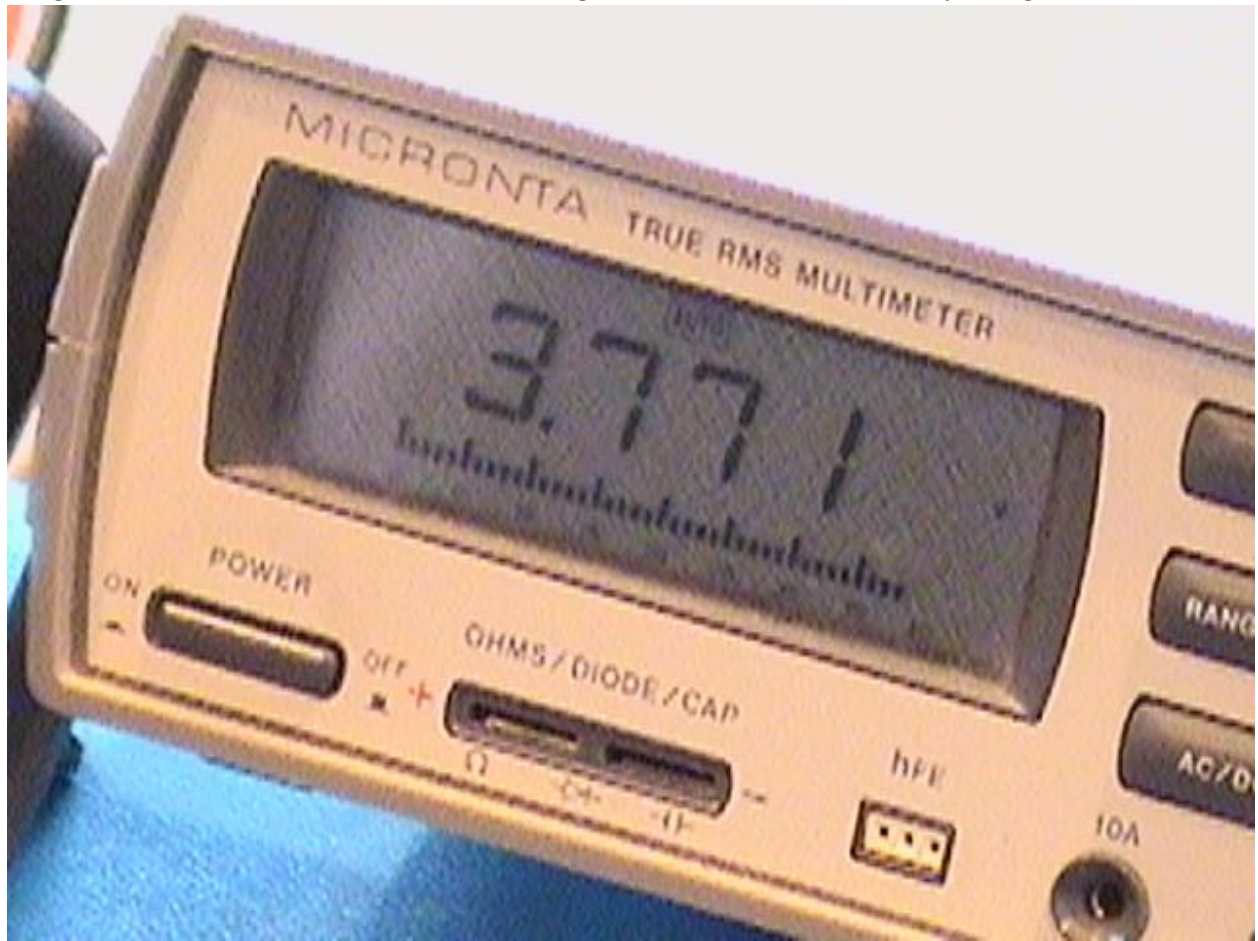


Image G – “Bird A” view from the Fox-1 Cam gives a great view of the stack on the breakout board

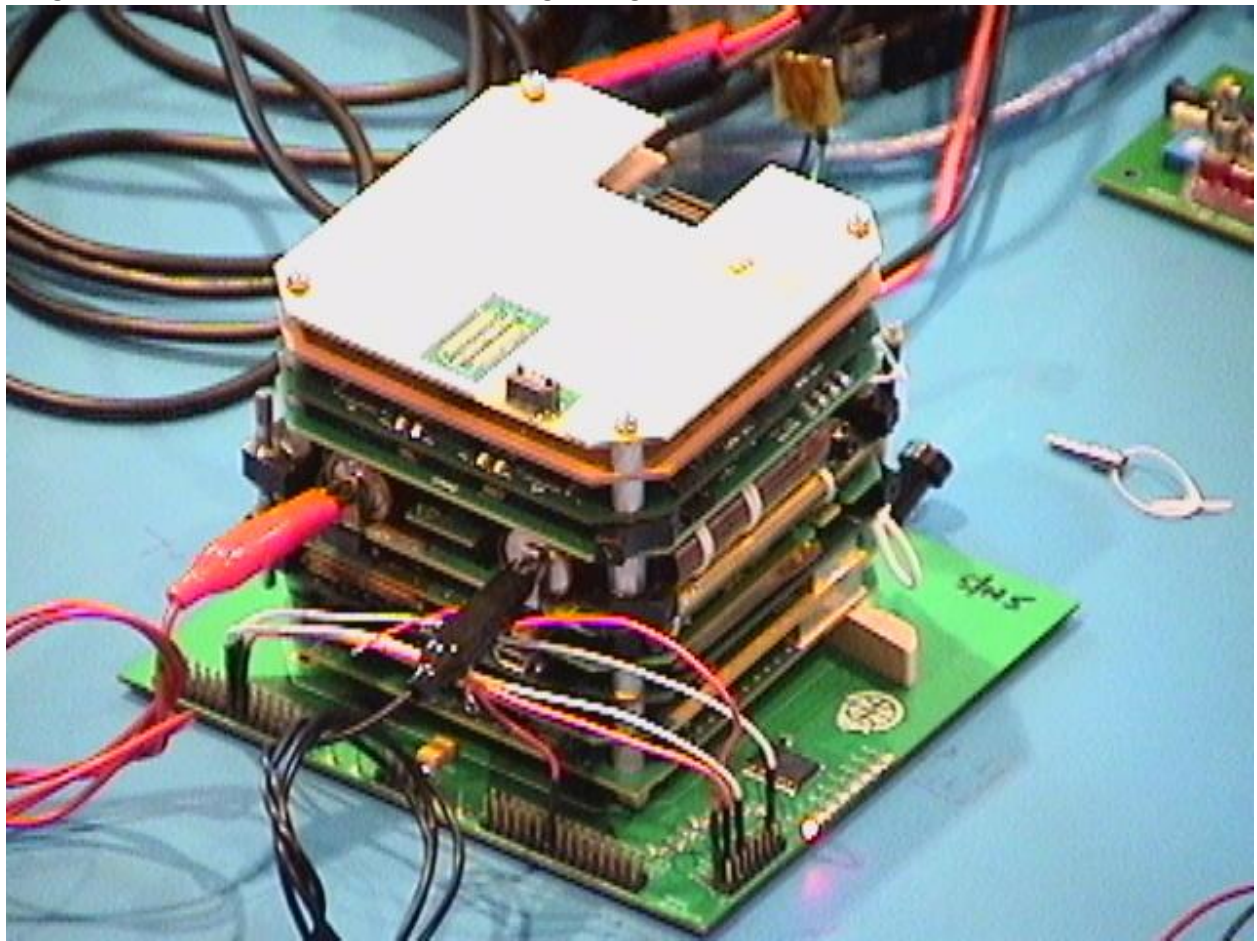
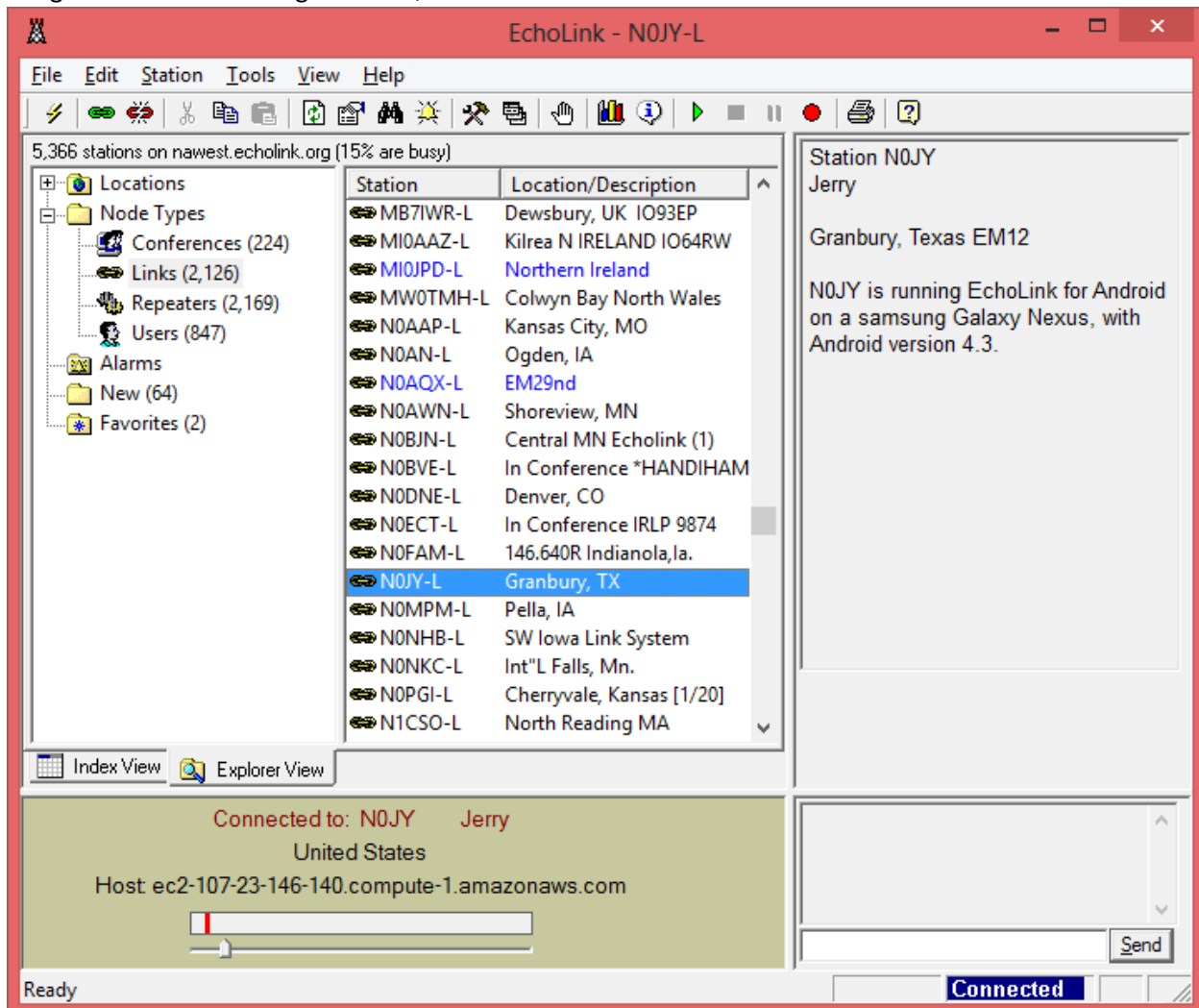


Image H – looking over my shoulder at my laptop with telemetry readings via the umbilical connection

Telemetry data displayed on the laptop screen:

Parameter	Value
+X	0001
-X	0001
+Y	0001
-Y	0001
+Z	0002
-Z	0001
Card Temp	2056
PSU Current	0008
Calculated Spin	0000
RF Cards	Temperature
Transmit	2074
Receive	2066
Antenna	1
THU:	
MCU Temp	43C
X SpIn (MEMS)	2119
Y SpIn (MEMS)	2073
Z SpIn (MEMS)	2041
get status	
For MCU serial number	0x0.cb6b3494.a1af5e50:
(Overflow: 1368, no overflow: 7955291, in RELAY or BEACON	
Vbatt/2 reading is	2693

Image I – Echolink running on the NØJY shack PC



The Fox Whistle Experiment

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Abstract

At the start of the telemetry beacon transmissions, the Fox-1A satellite will send a brief unmodulated carrier burst. This paper discusses and proposes some applications and uses for this carrier signal in future ground station software.

Introduction

The flight software for the Fox-1A satellite has been written to send the telemetry as a sub-audible signal on the FM downlink. Normally this signal will be sent continuously while user signals are being sent, through the transponder. However, if the transmitter is idle for two minutes due to the lack of an uplink signal, then the flight software will turn on the transmitter and send a telemetry beacon. A unique feature of the Fox-1A telemetry beacon is a sub-second burst of unmodulated carrier at the start of the beacons. Following the carrier, a “current telemetry” frame is sent, and then, a second telemetry frame is sent simultaneously with a voice recording.

Since the carrier is unmodulated, ground station software with an appropriate receiver, which could be as simple as a FUNcube dongle, can be programmed to look for the carrier with a fast Fourier transform (FFT). Following the carrier, the telemetry frame acts as both a confirmation that this burst came from an amateur radio satellite and as a signature that this burst came specifically from Fox-1A. Part of the telemetry frame is a satellite ID number which identifies the telemetry as coming from Fox-1A.

The unmodulated carrier can be thought of as a “whistle” [1] announcing the presence of the satellite at a particular time and at a particular frequency. Ground station software can use the unmodulated carrier to estimate the observed frequency of the downlink and improve the demodulator’s ability to demodulate the subsequent telemetry frames. In addition, the carrier itself is useful as a measurement. The same ground station software can report the observed carrier frequency [2], the date and time [4], and the exact latitude and longitude of the ground station receiver to a centralized server on the Internet where all of the observations from multiple ground stations can be collected over time.

With a number of observations over time from multiple ground stations, it becomes possible to compute the difference between the expected times and frequencies and the

observed times and frequencies. From these differences, the satellite's Keplerian elements could be computed and updated.

In addition, the same software can monitor the frequency of the downlink while user signals are passing through the transponder, and it can identify the time of closest approach (TCA). The sub-audible telemetry on the downlink will once again confirm the identity of the satellite as Fox-1A. TCA is a better measurement of both the time and the satellite's relative position than acquisition of signal (AOS) or loss of signal (LOS) because the LOS and AOS can both be corrupted by obstacles on the horizon such as trees, mountains and buildings. Also, at TCA the satellite is closest to the ground station and the downlink should be at its strongest and easiest to measure. Even though there is only one TCA per pass, there could be multiple beacons per pass if there is no uplink signal during that pass.

From multiple observations of TCA from multiple ground stations as well as the calculated differences between observed and expected frequency, this experiment hopes to be able to compute and update two line orbital elements (TLEs).

The ultimate success of the experiment depends not only on the successful launch of Fox-1A and on the ground station software but also on the availability of a sufficient number of capable and interested ground stations with good geographical separation. Interested amateurs, schools, or others are encouraged to contact the author by email.

The author welcomes comments and constructive criticism on this experiment as well as suggestions for features, enhancements and improvements.

Footnotes

[1] The name of the experiment "Fox Whistle" comes from the name of the satellite "Fox-1A" and is a pun on the term "wolf whistle." The difference being that a wolf whistle consists of two separate notes, one rising in frequency and one falling in frequency, whereas Fox-1A beacon's "whistle" technically only falls in frequency due to the Doppler effect.

[2] The observed carrier frequency, as observed at that ground station with an offset due to the Doppler shift as well as any possible ground station receiver offset/drift and any possible satellite transmitter offset/drift (perhaps due to age or temperature).

[3] [deleted]

[4] This will be the date and time as reported by the computer's operating system within the accuracy of the ground station computer's clock. If the data is sent immediately to a central server on the Internet, then the observation should arrive at the server within about a second, and the central server can validate the reported date/time of the observation as a secondary check.

Ballistically Reinforced Communications Satellite (BRICSat-P) : The Enhancement of the APRS Amateur Radio Network through Micropropulsion

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Abstract: CubeSat missions have become increasingly more important in testing new designs in low earth orbit, and their technology has become one of the main factors for contributing to the Amateur Radio Network for users worldwide. However, much of the attitude control systems for small satellites in the past have relied on passive controllers and chemical micropropulsion systems. These systems have low specific impulse values and are often not suitable for CubeSat applications due to their size, complexity, and power requirements. Electric propulsion systems have shown to have much higher specific impulse values that allow for advanced attitude control and stationkeeping, but their power requirements often make it not feasible for CubeSat applications and consume most of the CubeSat volume. Recently, The George Washington University has developed a Micro-Cathode Arc Thruster (μ CAT) system that produces specific impulse values up to 3000 seconds, while occupying less than one-half of the 1.5U CubeSat volume. The researchers at the United States Naval Academy and The George Washington University have successfully integrated the μ CAT onto the Naval Academy's Ballistic Reinforced Communication Satellite (BRICSat-P) and have shown through testing and computational modeling that the propulsion system is capable of sustaining CubeSat operations. BRICSat-P is a low cost 1.5U CubeSat that will demonstrate on-orbit operation of an electric propulsion system while performing radio communications using the multi-user PSK31 transponder developed by the Brno University. The propulsion system will be used for attitude control, orbit change, and de-orbit experiments. The goal is to show that the propulsion system adds flexibility to the Amateur Radio network through its support of the PSK31 text messaging transponder. This paper will present discussion on design tradeoffs, model/simulation results of the flight hardware and its expected performance on-orbit. The satellite is fully funded and scheduled to launch in March 2015.

I. Introduction

CubeSat missions have often been viewed as technology for performing small spacecraft experiments for the amateur science community. With the establishment of the amateur radio network, CubeSats found a new purpose to support this capability for users worldwide to have access. With this access, students from anywhere around the globe can perform different experiments and share scientific studies in accordance with the Amateur Radio License regulations. This establishment of the Automatic Packet Reporting System (APRS) brought an even greater capability for in establishing the network and ultimately CubeSats as an education force multiplier. Recently, CubeSats have become an important part of keeping the network alive through two Naval Academy satellites, PCSAT and the ARISS, which currently resides on the ISS. However, both are currently very unreliable due to their age and dependence on the ISS to allow for complete coverage for the APRS network. Moreover, CubeSat missions have become increasingly more important with the development of nanotechnology due to their significantly lower costs¹. Another CubeSat with APRS capability is needed to continue the vast network set forth by the Naval Academy. More importantly, in order for the CubeSat technology to continue to meet their mission demands and progress in the phases set forth by the AMSAT phase system, a feasible propulsion system is needed to support CubeSat operations. CubeSats rely mostly on their launch vehicle locations for maneuverability and altitude placement. Thus, an ability to place itself into a desired orbit and maneuver between orbits at ease can greatly

improve the scope and capability of the future satellite missions. However, the feasible application of an electric propulsion system, has never been successfully accomplished.

Currently, the most widely used micropropulsion systems are chemical thrusters. These propulsion systems often require complex feed systems and the use of a toxic propellant, hydrazine. Hydrazine micropropulsion systems can about 20 cm and have an operational life of two weeks to two years². In contrast, electric propulsion systems are more efficient in extracting thrust from the propellant as indicated by the higher specific impulse values (e.g. 3000 s for an ion thruster as opposed to 300 s for a monopropellant thruster)³. However, most electric propulsion systems require large amounts of power in kilowatt and megawatt range to start and sustain the propulsion system for long periods of time.

The Micro-Cathode Arc Thruster (μ CAT) developed by researchers at the Micro-propulsion and Nanotechnology Laboratory (MpNL) at The George Washington University has specific impulse values of approximately 3,000 seconds will drawing only 0.1 Watts of power. The entire system has a mass of 300 g and an approximate volume of 541 cm³, which can be integrated on all CubeSat systems. When fired at 1 Hz operation, the thrusters are capable of lasting up to ten years in operational life with no spacecraft contamination. This would significantly increase the life expectancy of CubeSats and longevity for the Amateur Radio network through space. The main objective for the BRICSat-P research team was to successfully integrate the μ CAT system onto a 1.5U CubeSat and validate its use for future CubeSat applications through its performance of three maneuvers in space while providing radio communications through the PSK31 transponder: de-tumbling, spin maneuvers, and a delta-V maneuver. Computational modeling using MATLAB Simulink and the Systems Tool Kit was used to accurately plan the BRICSat-P mission through performance predictions and fully analyze the capability. This paper will discuss the ultimate capability and possibilities that a propulsion system brings to the Amateur Radio Satellite Community (AMSAT).

II. Thruster System Design

The thruster PCB has been designed for two channel thruster mounts. This modular design allows a variety of thrusters to be placed in a satellite bus away from the microcontroller to allow for customization depending on mission requirements. For the BRICSat-P mission, a design for 4 μ CATs all facing one direction had been selected.

Two thruster boards are stacked around the control PCB to minimize footprint. Consisting of a Power Processing Unit (PPU), power is regulated and generated in pulses to produce the necessary current for the thruster discharge. A micro-cathode arc thruster (μ CAT) works by creating plasma between a cathode and anode and accelerating ions outward to produce a thrust. An arc needs a medium to move through; however, initially, there is nothing to travel through. To overcome this, a thin conducting layer is coated onto the insulator separating the anode and cathode.

As the coating heats, a vapor is produced which allows for the arc to form. The arc originates from the cathode at a point called the cathode spot. This spot is where material is evaporated to create an arc travel medium and where ionization occurs to produce thrust. An external magnetic field is applied to allow for efficient expulsion of plasma from the thruster. As shown in Figure 1, the PCB has been designed for all components to be located on one portion of the board.

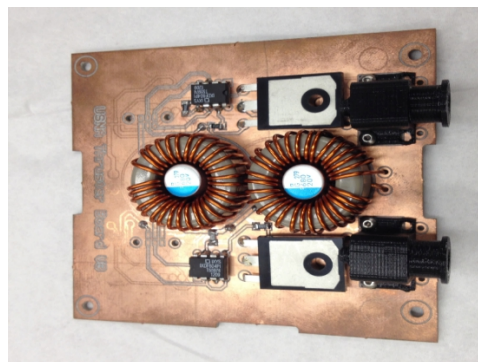


Figure 1: Model of the PPU PCB.

III. CubeSat Model

The main objective was to integrate as many thruster systems in the 1.5U CubeSat that would be able to support attitude dynamics and control simulations without drawing too much power to prevent the use of the PSK31 radio for the Amateur Radio Network and communicate with the Naval Academy ground station. A mass and volume budget was created, and each component was modeled to be integrated into the full satellite. It was finally decided that four thruster systems were capable of fitting into the 1.5 U CubeSat. The command data and handling systems, PSK31 radio, and power systems composed half of the CubeSat volume, leaving 6 cm available for the thruster systems. A camera was also added to allow for pictures of the plasma plumes and thruster operations to be taken and sent to the ground stations for documentation. Figure 2 shows the final design for BRICSat-P with the integrated thruster systems and appropriate coordinate system. Due to the large availability of space, the thruster systems were placed to straddle the CubeSat's center of mass in order to allow for two axes control of roll rates. The thrusters were placed in this box-like fashion (x-wing design), since the computational analysis showed that this configuration allowed for the easiest delta-V scenario combined with the fastest results for de-tumbling and spin control.

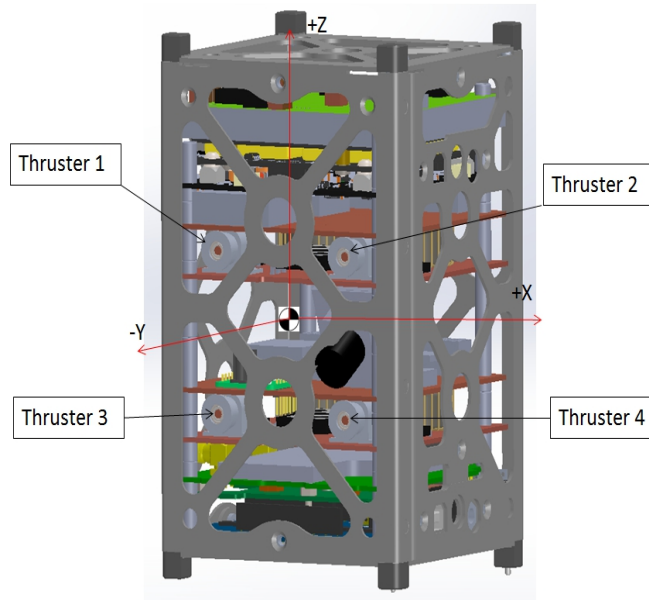


Figure 2. Final design of BRICSat-P.

IV. On-orbit Mission Demonstration Analysis

There are three missions that the BRICSat-P will perform in orbit. After initial expulsion from the launch vehicle, BRICSat-P will begin de-tumbling operations autonomously. After the three inhibits, the gyro will take measurements; and the thrusters will begin firing to stabilize the structure within 1 deg/sec in all three axes. SolidWorks was used to determine the mass properties of the BRICSat-P design. This information was integrated into the MATLAB Simulink model that was created to simulate the BRICSat-P mission with the space environmental effects in order to generate a control algorithm for the thrusters and predict its performance in orbit. Different placements and configurations were analyzed to determine the optimum placement for the thrusters. It was ultimately decided that 4.5 cm of thruster separation produced the quickest de-tumbling results within 7 orbits coupled with the available space to allow for the camera to be placed above the thrusters. Dummy masses could also be placed within the satellite to further alter the inertia tensor in order to make the major axes more defined from the intermediate axes, which is uncontrollable due to the thruster configuration. The de-tumbling results are shown in Figure 3.

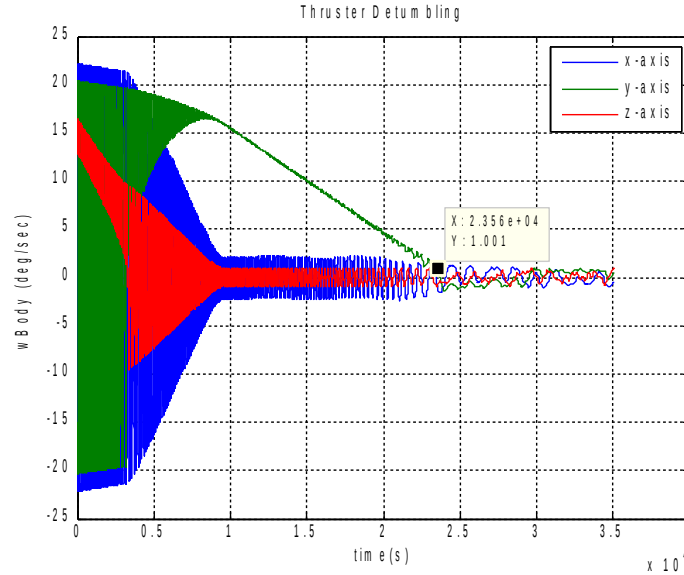


Figure 3. This plot shows the de-tumbling when the thrusters were placed at the optimum configuration.

As shown in Figure 3, the satellite stabilizes to the desired range. The y-axis is the intermediate axis, which is uncontrollable, since the thrusters are not canted. As a result, momentum is constantly being transferred from the intermediate axis to the major axis as the thrusters stabilize both the major (x-axis) and minor (z-axis) axes. Calculations were also performed for the second mission. It was found that enough power and force was available to spin and de-spin the thrusters in a stable manner while sending pictures to the Naval Academy ground station. The thrusters will spin the structure to 20 revolutions per minute for ten minutes. Afterwards, the thrusters will shut off, allowing for the camera and other systems to communicate with the ground station for the next seventy minutes. The final ten minutes will be used to stabilize the satellite to complete the 90 minute orbit cycle.

Power analysis was performed to determine the amount of power that was needed to perform the operations. The thrusters have been designed and tested to only draw 1 Watt of power for one thruster to fire at a rate of 10 Hz. MATLAB and STK were used to analyze the amount of solar power that would be available for the satellite during each orbit. It was determined that each orbit provided an average orbit power of 3.25 Watts. This demonstrates that the thruster operations can be supported by solar power alone. Furthermore, utilizing a 50% duty cycle also decreases the power requirements. This is significant, since most electric propulsion systems require the use of a secondary power source. This increases the life and capability of CubeSats in orbit.

V. Future Capabilities

The final mission for BRICSat-P is to demonstrate a capability for orbit change maneuvers. Currently, the system integrated onto the 1.5U CubeSat has an effective delta-V of 2.454 km/sec. This delta-V gives the satellite the capability of making significant orbital altitude changes greater than 2,000 km and inclination changes greater than 5 degrees through a gentle spiral transfer, which has yet to be demonstrated for an electric propulsion on a CubeSat. A simulation was performed in MATLAB for the current satellite to perform a 5 degree orbit transfer. The results are shown in Figure 4 that indicate the transfer is possible within two years.

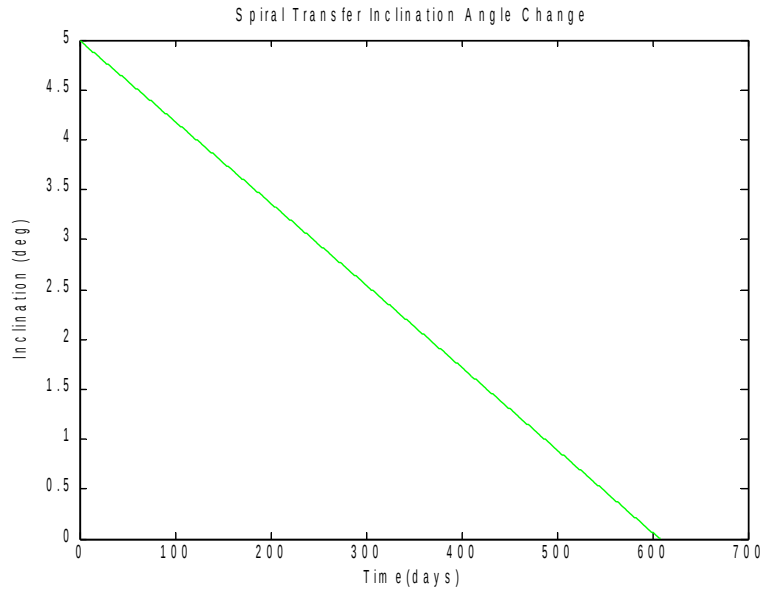


Figure 4. This plot shows the inclination change performed by the μ CAT thrusters.

BRICSat-P contains only a magnetometer and gyro. Thus, it does not have the capability for three axes control. Currently, the concept of operations is being generated to align the CubeSat with the Earth's magnetic field and perform a delta-V operation for an inclination change of 5 degrees. The goal is to fully validate the thrusters for CubeSat missions and show the full capability of CubeSats when they are equipped with feasible propulsion systems. The models in Systems Tool Kit have even shown that the thrusters are capable of supporting Lunar missions if they are equipped with enough propellant.

VI. Conclusion

The successful design and integration of the microcathode arc thruster by researchers at the George Washington University and the United States Naval Academy represent a significant breakthrough in the field of CubeSat micropropulsion. As shown in the analysis, the propulsion system is feasible to support radio communications without drawing power from the secondary power source and can perform sophisticated orbital maneuvers. This opens more possibilities for the AMSAT community to further expand the capability of the global network and eventually reach the AMSAT's higher phases of geostationary orbit and lunar missions, which require on-orbit stationkeeping delta-v's only attainable by active propulsion systems. Not only will the propulsion system be stabilizing the satellite, but the PSK 31 radio will be fully operational providing communication for users and students worldwide so that they can perform amateur science experiments to further enhance their learning. The space frequency of 145.825 MHz is a must for users and is needed for the continuation of full-time availability of the APRS network, since the existing two satellites are almost completely unreliable. The demonstration will fulfill the BRICSat-P initiative, which is to increase the lifetime of satellites in order to push the CubeSat to realize its full potential. The final thruster systems have been fabricated, and the satellite has been fully constructed and flight qualified. It will launch in March 2015 and be available for users worldwide.

VII. References

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²"Hydrazine Thrusters." *Space Propulsion For the Access, Utilisation and Exploration of Space*, 2014. <http://cs.astrium.eads.net/sp/spacecraft-propulsion/hydrazine-thrusters/1n-thruster.html> (accessed December 14, 2013).

³Sutton, George P., and Oscar Biblarz. ***Rocket propulsion elements***. Hoboken, N.J: Wiley, 2010.

PSAT – An APRS and PSK-31 Transponder

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Abstract: PSAT is a Naval Academy student satellite project named in honor of one of our graduates, Dr Parkinson of GPS fame, which contains a packet radio communications transponder for relaying remote telemetry, sensor and user data from remote users and amateur radio environmental experiments or other data sources back to Amateur Radio experimenters via a global network of internet linked volunteer ground stations as illustrated in Figure 1. The data transponder also includes all telemetry, command and control for a complete cubesat. A secondary transponder supports an additional multi-user PSK31 text messaging transponder which was built by students at Brno University in the Czech Republic under the mentorship of Mirek Kasal. OK2AQK.

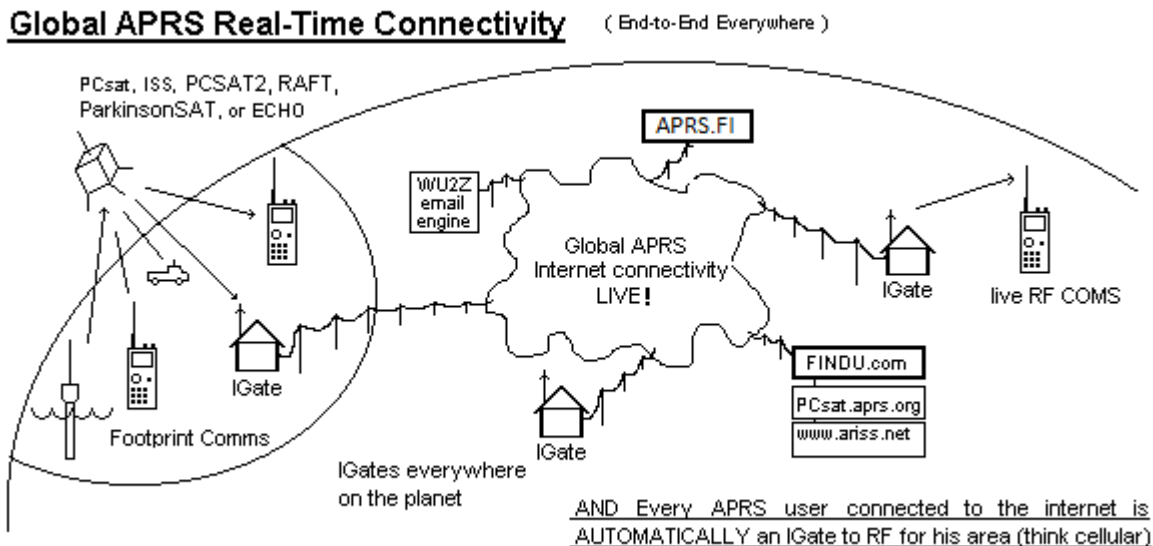


Figure 1. The global APRS network consists of terrestrial as well as internet and satellite links.

Operations in the Amateur Satellite Service: Both of the transponders on PSAT are operated in the Amateur Satellite Service to encourage amateur radio students, educators and experimenters around the world to contribute additional satellites to this constellation on 145.825 MHz or to build interesting self motivated remote sensors suitable for the uplink channel. This kind of Amateur Radio experimentation fits well in the ITU rules [1] for operating in this service and well serve our educational and outreach goals for student projects encouraging young people to be interested in Science, Technology, Engineering and Math.

APRS Packet Transponder: The APRS packet transponder is a 1200 baud AX.25 Packet Radio Relay similar to what is flying on PCSAT since 2001 and the ARISS experiment on the ISS. This ongoing mission in space on the original PCSAT [2] is now over 12 years old and pioneered this very popular operating mode via the ISS since 2006 [3]. Both of these missions

deliver packets to users worldwide via the global network of volunteer ground stations feeding the two downlink capture pages, <http://pcsat.aprs.org> for PCSAT and <http://ariss.net> for the ISS. These pages display live maps of the most recent user position data and capture all message traffic between users.

PSK31 Transponder: The PSK-31 multi-user FDMA transponder[4] experiment built at Brno University is similar to what we flew on RAFT [5] and PCSAT2 [6]. The users on the ground see a common PSK31 waterfall as shown in Figure 2. Despite the very high 18 kHz Doppler on the UHF downlink, all users will see the same waterfall display without Doppler because the downlink is simple FM audio. The users will of course have to re-tune their FM receivers 5 times during the pass in 5 kHz steps to stay in the passband, but the Doppler is not added to the linear signals in the audio passband.

The multiple PSK-31 users transmit using SSB on the 10 meter uplink. There, the Doppler is linear but because it is 14 times lower in frequency than the typical UHF downlink, the total Doppler shift is only about 1 kHz over the pass and typically on the order of about 1 Hz per second during the lower elevation portions of the pass. This portion of the pass can usually be tracked by existing PSK31 decoding software. Users are responsible for adjusting their transmit frequency to place themselves at the desired location in the waterfall passband that everyone shares.

The peak Doppler shift during a LEO pass, however, can be as high as 6 Hz per second at the center of a high elevation pass. Hopefully, PSK31 decoding software authors will revise their code so that their DSP algorithms can monitor their own uplink in the downlink and adjust their uplink in real time to maintain the needed under 1 Hz per second rates on the downlink.

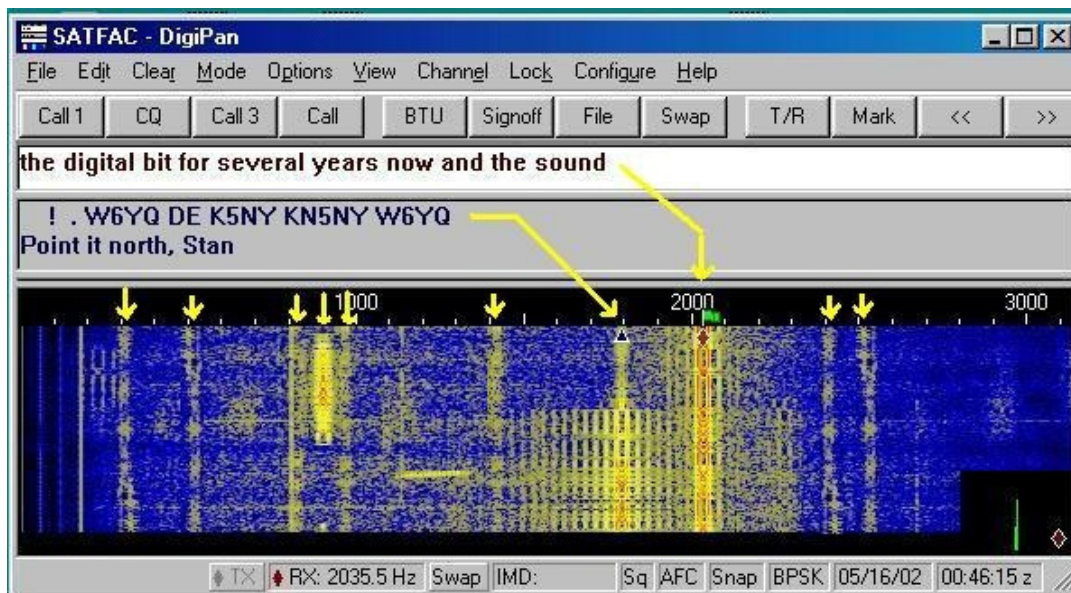


Figure 2. The downlink waterfall display is identical for all users since no Doppler is added by using FM.

This PSK31 text messaging transponder allows messaging between up to 30 modest ground stations simultaneously. In the example waterfall display above, 10 users are clearly visible. Each user transmits a 31 Hz wide narrowband transmission within the 3 kHz wide transponder, and all can be seen simultaneously via the UHF FM downlink. Uplink stations do not need gain antennas on the HF uplink but can use a vertical monopole antenna and 5 Watt SSB transmitter to give the transmit antenna profile as shown in figure 3.

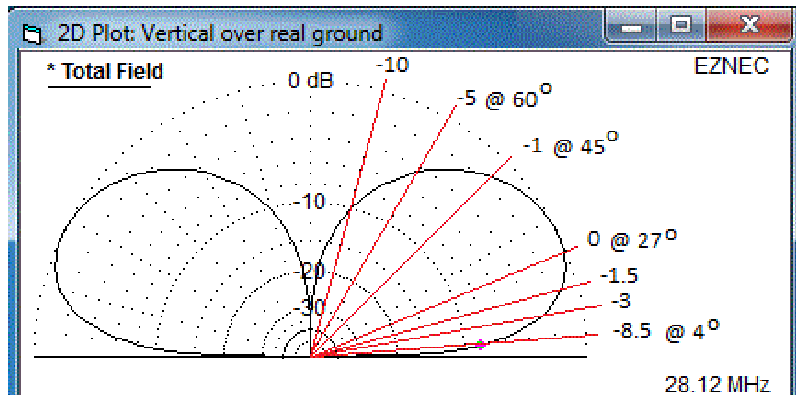


Figure 3. The antenna pattern of a typical $\frac{1}{4}$ wave vertical matches very well the range gain/loss of a typical LEO orbit.

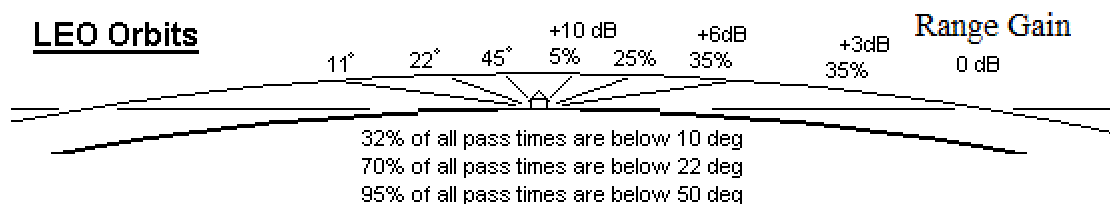


Figure 4. The LEO geometry has over 10 dB of range gain as the satellite rises in elevation.

To calculate the PSK31 link budgets [7] we combined the user TX antenna gain profile with the variation in range gain from the horizon to over 60 degree elevation as shown in figures 3 and 4. The combination gives an uplink power variation per user of less than ± 4 dB over 90% of the duration of the pass. Unfortunately, however, the 6' HF receive antenna is not cross polarized (as shown in figure 5) and so there will be periodic fades as the spacecraft rotates.



Figure 5. Then antennas are cros polarized whips on VHF and UHF but linear on HF.

CUBESAT MODEL: In 2008, we re-designed the original PSAT to fit inside the specifications for a 1.5 unit cubesat so that two PSATs could be launched from the same P-Pod launcher. Half of the 1.5 unit PSAT was available for auxiliary payloads or experiments. In this extra space is where we placed the Brno University PSK31 experiment. The current 2014 design remains a 1.5U cubesat but with higher efficiency solar cells, we no longer need the deployable side petal panels and can operate with fixed side panels as shown in the right of figure 5.

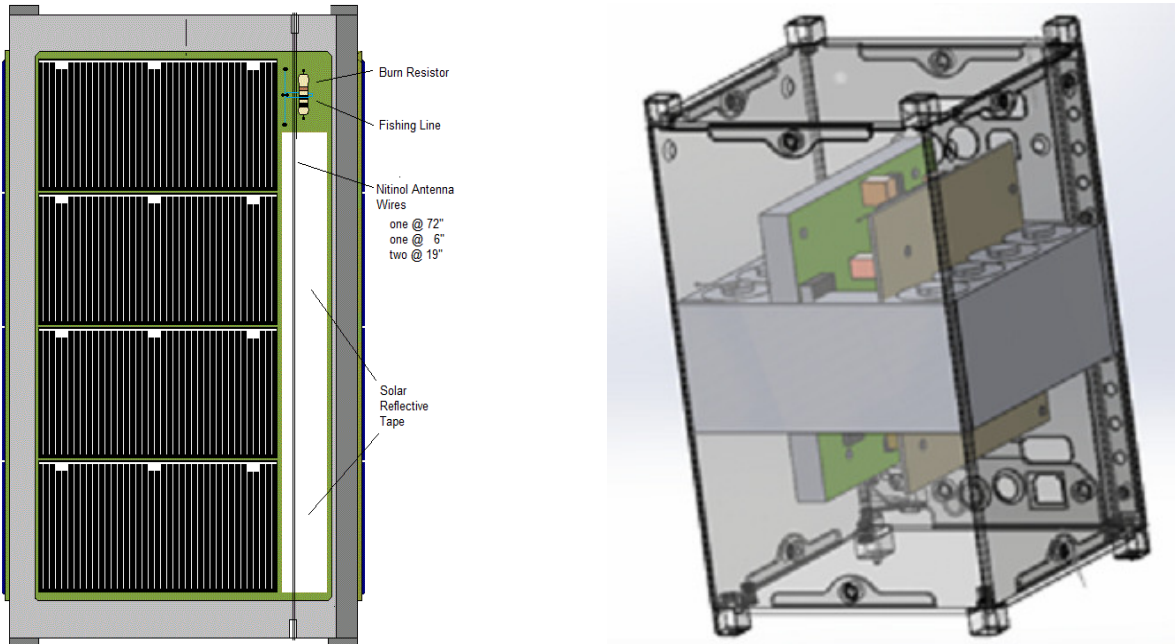


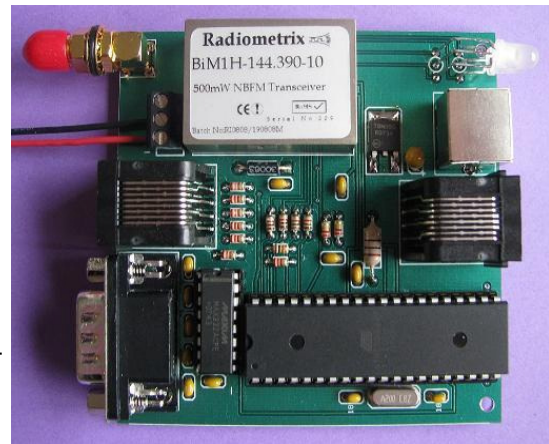
Figure 5. The side panels are unique for charging the NiCd's in parallel and the mass is concentrated at the center to maximize the Z axis moment of inertia.

Unique Power System: This model with the 4 large and efficient solar cells per side is designed around a unique battery system. Since the total solar voltage per side is only 3.2 volts (0.8 volts per multi-junction cell) we cannot charge the complete 9.6v battery string, but can charge two NiCd cells per solar panel. These 4 side-panel/NiCd-pairs are operated in series for the 9.6v bus, but are charged in parallel. This parallel charging of no more than two NiCd's in series per solar panel reduces one of the primary problems with spacecraft battery charging which is the uneven charge balance that accumulates when entire strings are charged in series.

Attitude Control: The primary attitude control requirement is to evenly expose the four side panels to the sun so that the NiCd cells are equally charged and to even-out the thermal load on the panels. A very slight spin about the Z axis is maintained by the unbalanced solar radiation pressure on each side. A highly reflective strip on the counter-clockwise edge receives greater radiation pressure than the momentum transfer to the mostly black solar panels. This should create a fractional RPM spin (the spin on PCSAT now, 12 years in orbit is maintained between

To maintain a very slow spin about what would normally be an unstable Z axis, the mass of the spacecraft is concentrated at the center and out to the X and Y sides. In the X-ray view of figure 5, you can see the large stainless steel masses that surround the batteries and hold them in the X and Y extremes to give the Z axis the greatest moment of inertia.

Maintaining the Global Experimental Data Channel: The space frequency of 145.825 MHz is the space segment of this initiative to encourage both new satellite construction in support of this experimental data channel and lower cost buoy and sensor experimentation at other schools. With PSAT we hope to continue the ongoing full time presence in space of the 145.825 data uplink channel for future experiments. To this end we hope other schools to either build additional 145.825 MHz relay satellites and/or to build experimental sensors. The complete communications system including data transponder is simply an off-the shelf APRS MicroTracker from Byonices.com that fits on one 3.4 inch square card shown in figure 7. Though this particular card is no longer available, other such hardware can be easily adapted for the purpose.



We hope that PSAT will be the Egg in this chicken-egg conundrum and encourage more transponders in space to carry on this very valuable Amateur Radio capability.

- [1] <http://aprs.org/psat/IARU-rules-psat.txt>
- [2] <http://aprs.org/psat.html>
- [3] <http://ariss.net>
- [4] <http://aprs.org/psk31uplink2.html>
- [5] <http://aprs.org/craft/save-raft.html>
- [6] <http://aprs.org/psat2.html>
- [7] [http://aprs.org/PSK31/PSK31 Link Budgets for Psat-b.doc](http://aprs.org/PSK31/PSK31%20Link%20Budgets%20for%20Psat-b.doc)

\$50sat, one of the first four Pocketqubes – the Next Small Thing In Satellites

Submitted by:

Michael Kirkhardt KD8QBA, Stuart Robinson GW7HPW, Howie DeFelice AB2S

The success of the Cubesat has driven the cost of educational space beyond the means of many institutions and amateur radio operators. The co-developer of the Cubesat, Prof. Bob Twiggs came up with the idea of taking the next leap downward and reduced the footprint of the Cubesat to a quarter of its size. This new form factor of 5cm cubed was dubbed the “Pocketcube”. On November 21, 2013 four Pocketqubes were launched from the Unisat-5 satellite. One of these was \$50sat.

Genesis of a Pocketcube:

The \$50sat team consists of three hams, Michael Kirkhart KD8QBA, Stuart Robinson GW7HPW and myself, Howie DeFelice AB2S. One of the most often asked questions of the \$50sat team is how three hams got to launch their own satellite. A small part of the answer was being at the right place at the right time, but the majority of the answer was the enthusiastic support of Prof. Bob Twiggs and Morehead State University.

It all started when Michael and myself attended a hackerSPACE Workshop in Lexington, Kentucky in November of 2011. This meeting was organized by Prof. Twiggs and sponsored by KentuckySpace Inc. It brought together a wide range of educators and students that all had an interest in space science of varying levels of experience ranging from none to already successfully launching spacecraft. There were a few hams present and there was no question they formed the majority of the communications experience in the group. Prof. Twiggs introduced the idea of the PocketCube at the conference and that he had a launch opportunity with the University of Rome on the Unisat 5 satellite for two PocketCubes. Similar to the way that Cubesats are referred to as 1U, 2U,3U etc., PocketCubes are referred to a 1P, 2P and so on, with 1P equal to 1/8 of a Cubesat ,5cm cubed.

The first satellite would be a 2.5P PocketCube built by engineering students at Morehead State University in Kentucky and Sonoma State University in California named Eagle1. The second satellite would be a 1.5P PocketCube built by high school students that were part of an advanced studies program run by Prof. Twiggs to be named Eagle2. Both of these satellites would be launched into a 700 km, sun synchronous orbit. Prof. Twiggs put out a call for volunteers to assist in the development of these satellites through weekly webinars. Michael, myself and several others volunteered and the fun began.

Early on the group had decided on using the RFM-22 by Hope Electronics as the telemetry radio primarily because of its small size and operational features as well as its capability to operate in the 70 cm amateur satellite frequency band. There was much discussion on the processor. The Eagle1 team decided to use an MSP430 variant using

Micro-Logo programming language that the Morehead team developed for the MSP430. The Eagle2 team decided on using a PICaxe processor because of the easy to use and well understood BASIC programming language. One of the team members, Charlie Cantrill, found a ham in the U.K. (Stuart Robinson GW7HPW) on the PICaxe website that had done quite a bit of work using the PICaxe with an RFM-22 radio and invited him to join the team.

The Eagle1 team was making good progress but the Eagle2 team was having trouble getting traction. As the tentative launch date got closer it became apparent that Eagle2 was in trouble. In September of 2012, Prof. Twiggs asked if Stuart, Michael and myself would be interested in completing the Eagle2 project ourselves and by the way, we needed to have it done in 60 days. After a few seconds of thought we all agreed we would give it our best shot and \$50sat was born.

The mission:

The original goal of Eagle2 was to give new engineering students practical experience in the process of designing space systems. Having all worked with the students early on we realized that the problem in getting the project moving forward was the lack of an established starting point. PocketQube was an entirely new concept so there was no history for students to build on. The student team was more than capable but time was not on their side. It would take more than one semester to research all the required information, decide on a design and then make it all work. We decided to make \$50sat a template for a base platform that future students could use as a starting point. The design had to be simple, low cost and easy to reproduce. The entire project had to be completely open source. All of the schematics, PCB layout, BASIC code, parts lists and information about how the satellite works is currently available on a Dropbox account linked to the \$50sat website, <http://www.50dollarsat.info>.

Design and Proof of Concept:

The mission required that the satellite be simple, low cost and easy to reproduce. We were also limited to the size of a 1.5P PocketQube, 50mm x 50mm x 75mm. Our target weight was 200 grams. These design requirements drove several key decisions:

1. No “rad hardened” parts. Everything used had to be commercially and readily available. All the parts, except for the solar cells, came from distributors regularly used by hams.
2. All the PCB’s will be designed to fit a 1P (50mm x 50mm x 50mm) PocketQube. If the design was to be universal, it had to work in the smallest form factor available. Therefore, we decided on a 40mm x 40mm PCB outline.
3. The PICaxe processor would be used. The BASIC language is easy to understand and modify.
4. The Hope Electronics RFM-22B would be used as the radio. This radio is the smallest complete UHF transceiver commercially available today.
5. The battery would be an off the shelf lithium ion and fit in the same area as the PCB’s.
6. The antenna will be a half wave, measuring tape dipole.

With the design requirements finalized there were a few areas we were not quite sure about:

1. Could we generate enough power to maintain a positive power budget?
2. Would the battery survive the space environment?
3. Would the RFM-22B radio perform well enough to allow the transmitter to be turned off once in orbit and was 100mW enough power to capture telemetry?

Hardware elements:

RFM-22 radio:

This module manufactured by Hope Electronics¹ and available through Sparkfun² electronics is based on the Silicon Labs³ Si4432 ISM radio integrated circuit. This is truly a complete frequency agile digital transceiver on a 4mm x 4mm chip. The radio makes use of a SPI bus for control and communications with the on board packet handler. It also offers discreet I/O that can be used to externally access the mod/demod data path. Other significant features include AFC, on board reference crystal trimmer, RSSI measurement and non-volatile settings.

PICaxe processor:

The processor is a Microchip⁴ PIC PIC18F45K22 with a BASIC interpreter loaded into protected memory by Revolution Education⁵. PICaxe BASIC is a powerful language specifically designed for the PIC processor. It has many built in commands that take advantage of the many embedded peripherals of the PIC processor. Both flash and eeprom memory were used in the \$50sat project. In addition to the RFM22B radio and PICaxe processor, the processor PCB also contains a Maxim Semiconductor⁶ MAX6369 watchdog timer and DS18B20 temperature sensor. A TC1262 LDO regulator and TC54 voltage supervisor round out the power supply.

Max Power Point Tracker:

With such a small surface area, getting the most power possible from the solar cells was important. This was also an area that the team had little experience in. After considering several methods we decided to use a fixed power point tracking method. The thinking was that a small satellite with only passive stabilization and no damping mechanism would be moving around quite a bit in an unpredictable manner. Trying to track the max power point actively would be a rapidly moving target that would probably require a separate processor. This would also require significant development time, which we didn't have. The fixed power point tracker circuit was based on the Linear Technology⁷ LTC-3105 integrated circuit. Each side of the spacecraft had three pairs of Spectrolab⁸ TASC solar cells. Each series pair produces 4.4 volts at 28 mA at the max power point. Three sets of cells

would ideally produce 84 mA in full sun. The Max Power Point Tracker board has four LTC-3105s, one dedicated for each side of the spacecraft. Each of the four solar panels are connected to its own LTC-3105 circuit. The output of all the LTC-3105s was summed together in a diode “OR” configuration. An added feature of the LTC-3105 is the on board boost regulator which allowed us to set the output of each panel to 3.9 Volts to trickle charge the battery. The MPPT board also contained current sensors for battery and composite solar current as well as voltage test points for solar and battery voltages. All these points are fed back to the processor A/D for producing telemetry. A solar panel shutdown line allows solar panel output to be turned off when the battery is too cold to be charged.

LiOn battery:

The selection and availability of space rated batteries is fairly extensive and quite expensive, except if you need to fit them into a PocketQube. There is no known space rated batteries that would work for our application. There is surprisingly little environmental performance information on commercial Lithium Ion batteries, other than they should not be charged below 0 degrees C. The decision was to find something that fit and hope for the best. The winner was a Kodak KLIC7002 camera battery. Its basic dimensions of 27.3mm x 37.2mm x 6.7mm allows it to fit nicely within a 1P PocketQube envelope. It provides 3.7V with a capacity of 700 mAh, and was available for \$6.99 from BattDepot.com. If it would survive vacuum-bake testing, we should be good.

Antenna:

The original thought was to use a quarter wave monopole along the Z axis of the satellite. The problem with this idea was that a PocketQube is too small to provide an effective counterpoise even at UHF. The second choice was the old reliable tape measure dipole. A Laird mix 28 ferrite bead⁹ on the feedline was used as a balun. This arrangement causes a fair amount of spin fade but signals from the 100mW transmitter have been good.

Stabilization:

Passive stabilization using simple bar magnets has been a well proven technique for stabilizing small satellites. Since “simple” was a key design element this was the obvious choice. A 6mm x 10mm round NdFeB magnet¹⁰ was used. No damping was used to average satellite motion.

Software Overview:

BASIC programming language:

Using a high level, interpreted language for writing the satellite control software would seem counter intuitive to many embedded hardware designers. In this case, it was the perfect choice to achieve the stated mission goals. The on board PICaxe interpreter allowed a test-as-you-build environment. Each bit of code could be tried as it was written, debugged and re-written without the use of offline compiling and reloading. Errors were found almost immediately and corrected on

the spot. Modern BASIC can be written in a structured manner making use of reusable code segments and orderly code branching. The final code is easily understood and with inline comments separate documentation is really not required.

Telemetry monitored:

The software measures and records the following parameters: Battery voltage, composite solar panel voltage, radio temperature, PCB temperature, solar charge current, transmit current, receive current and idle current. EEPROM corruption, SEU RAM check and RFM22 “smart reset” is tested each program loop. The EEPROM and SEU checks will be explained later. The RFM22 smart reset is a “feature” of the chip that is designed to enhance reliability by generating a reset of the chip when certain conditions are detected, such as low battery voltage, rapidly discharging battery voltage, voltage glitch and exercising the shutdown (SDN) pin. Anytime the smart reset function is activated, all the internal programming registers are reset to their default condition, which is usually not what they were programmed to. If this were to occur in orbit, it would be an unrecoverable failure and the end of the mission. To deal with this issue, all RFM22 register programming data is stored in both the PICaxe FLASH memory and EEPROM memory. If the processor detects that a reset has occurred, the programming information is re-written to the RFM22.

Power management:

\$50sat utilizes a real time, closed loop power management process to control power consumption based on battery charge state. The largest power consumer in the satellite is the UHF transmitter. Power consumption is regulated by extending the time between transmissions based on a measurement of the battery voltage as follows:

- 12.6 seconds if the battery voltage is more than 3800mv
- 25.2 seconds if the battery voltage is more than 3700mv
- 50.4 seconds if the battery voltage is more than 3600mv
- 126 seconds if the battery voltage is more than 3500mv
- 174.6 seconds if the battery voltage is more than 3400mv
- 226.8 seconds if the battery voltage is more than 3300mv

Testing:

*Range Testing in UK:*¹¹

Early on in the project we had questions concerning the performance of the RFM22 over long range. The radio was designed for very short range communication and the datasheet parameters were typical of short range devices. Receiver sensitivity was given in absolute minimum power with no reference to noise figure. On short links a kilometer or two, noise figure is not very important but on a 700 kilometer link it's crucial. We could not do a meaningful link budget without some idea of the system noise figure. To complicate matters further, the RFM22 is designed as a data radio so there is no access to the analog baseband to

make noise figure measurements. While I was trying to come up with a way to make the measurements with the test equipment I had available, Stuart and his older brother Neal set out to do a range test outdoors. One end of their link was an RFM22 and a PICaxe programmed to send a known pattern in a loop with decreasing power levels each time through the loop until minimum power was reached. Once minimum power was reached the loop repeated starting at the highest power again. The maximum transmit power was 100 mW. At the other end of the link was another RFM22 and a PICaxe programmed to indicate when a packet was successfully received. Using unity gain antennas on both sides of the link, a maximum range of 40 kilometers was achieved on a line of sight over water path. Using the known power and path loss we estimated that the system noise figure was about 18 dB. At a 5 degree elevation we would have a slant range of 2600 kilometers. We would need an EIRP of 55 dBm (36 Watts into a 10 dBi beam) to command the satellite. Based on this we were confident we could send commands to the satellite to turn off the transmitter if required.

*Thermal chamber testing in Michigan:*¹²

The RFM22 is a very low cost module designed for short range applications. There was a concern as to how well this low cost radio would perform or even survive the wide range of temperature change encountered in orbit. Michael was able to obtain access to an environmental chamber and test the RFM22 over the range of -20C to +70C. Testing showed the radio was operational over the entire range. The frequency variation as a function of temperature change was approximately 7 KHz from -10C to +70C. It would have been possible to build a lookup table in software that compensated for this variation but we chose not to since the variation due to Doppler was already moving the frequency more than this over a much shorter period.

Power generating and control testing by Michael and Stuart:

Actual measurements confirming the power generating capability and the robustness of the design needed confirmation. This testing was mostly done using the actual design hardware and solar cells while outside in available sunlight. With sun on one side of the spacecraft we could maintain a positive power budget even below the earth's atmosphere. Michael made detailed measurements of power generation vs consumption for all the satellite modes and average power consumption during each telemetry cycle. Stuart ran days of "torture testing" of the entire system by leaving a satellite system running in his "garden" unattended for days. This exercised all the elements of the power control system: battery power management, low battery shutoff and charging operations. Even though the satellite went into idle mode when the battery got below critical levels, operation resumed soon after sun was on the solar panels.

Max Power Point measurement:

The Spectrolab datasheet indicated that the maximum power point for a single cell was 2.19V. One would think that if two cells were in series the max power point would be twice that or 4.38V. Testing of the first version of the max power point

tracker circuit were below expectations. I ran several outdoor tests under average sun conditions as well as one test under a CFL light. Each test involved placing a 10 turn wirewound pot across a solar panel consisting of 6 cells in a series/parallel configuration. Voltage and current were monitored and recorded as the load was increased until the voltage dropped 100mV. The current was measured at that point. This was repeated until the short circuit condition was obtained. Power was plotted for each point and the maximum power point determined. The max power point consistently fell around the 3.0V range, so this is where we set the tracking point on the LTC-3105 controllers.

Modes of operation:

All of the following is explained in great detail in the \$50sat-Eagle 2 Communications document¹³. The \$50SAT communications and measurements are sequenced in a program loop that constantly repeats. This loop starts as soon as the initial set-up of \$50SAT has completed following a hardware or software instigated reset. The fast Morse and FSK RTTY are not sent at every program loop, but alternate according the values of a program variable. After the initial set up the \$50SAT program executes its tasks in a specific order. Its difficult to give precise timings for where in the program loops these tasks occur as the Morse messages vary in length as does the word per minute (WPM) rate. The fast Morse data takes less time to transmit than the FSK RTTY and the sleep time varies too. Its best to use the slow Morse beacon as a marker. Of particular note is that the listen period for command uplink is the 10 seconds immediately after the end of the slow Morse beacon and the transmission of a single 'ready' packet.

Slow Morse:

Once every program loop (approximately 1 minute at full battery charge) one of five call signs or messages is sent out as slow FM Morse, deviation of 5Khz. It is generated using the direct modulation input feature of the RFM22; the modulating source is one of the hardware PWM outputs available on the PICaxe. The sequence is:

- GW7HPW (telemetry is sent using RTTY)
- AB2S (telemetry is sent using fast FM Morse)
- KD8QBA (telemetry is sent using RTTY)
- S50SAT (telemetry is sent using fast FM Morse)
- EAGLE2 (telemetry is sent using RTTY)

The 'EAGLE2" message can be changed to a different message of up to 15 characters by command uplink from the ground; it has been changed 3 times thus far, and is currently set to MO76. The words per minute (WPM) speed of the Morse will increase as the solar voltage falls, and the tone of the Morse will be higher for a higher battery voltage as described below.

Morse WPM rate:

The WPM rate of the Morse is varied as the solar panel voltage varies. At high solar voltage the Morse WPM is reduced, and at low solar voltage it is speeded up. So by listening to the FM Morse you can tell if the solar voltage is high or

low. In addition at low solar volts where the battery charge is expected to be low also, the faster Morse uses less power. At 2500mV from the solar panels the delay value used for the Morse dit period is 50mS, this gives a WPM rate of approx 24WPM. At 4500mV from the solar panels the delay value used for the Morse dit period is 100mS, this gives a WPM rate of 12WPM.

Morse tone frequency:

The tones used for the Slow Morse beacon will vary as the battery voltage changes. The tone frequency is related to the battery voltage as follows: $\text{ToneFrequency} = \text{BatteryVoltage(mV)} - 2900$. For example, if the battery voltage is 3602 mV, the tone frequency will be 702 Hz. At 3300mV all transmissions are turned off, so there is little point in setting the Morse tone frequency for this low level. The limits used are 3400mV to 4300mV, although in normal operation the battery voltage should not exceed 3900mV.

Fast morse:

Every other run of the main program loop (so approximately every two minutes at full battery) key data is sent out as fast 120WPM FM Morse. This is too fast to decode by ear, but there are several PC based programs that will decode fast Morse, you just need to install the software and feed the audio from a UHF receiver, a simple HT will do, into a PC. Then tune into the slow Morse beacon, remembering that the Doppler shift may be as much as plus 10kHz as the satellite is coming towards you and as much as minus 10kHz as its going away from you. This gives a possible tuning range of between 437.515MHz and 437.495Mhz. The data sent in fast Morse is; battery volts, solar volts and solar current.

ASCII RTTY:

The RFM22B\Si4432 is also capable of generating FSK programmatically by using the frequency offset registers. These registers allow the carrier frequency to be offset in either direction in increments of 156.25 Hz. \$50SAT uses this feature to send telemetry via RTTY. The data format is 8 bits at 100 baud using a 625 Hz shift. This allows receivers capable of operating in lower sideband mode to receive the RTTY data. Most base station UHF transceivers can receive in LSB mode as can the Funcube dongle. The \$50SAT software sends the same bytes in the info packet as 8 bit ASCII FSK RTTY. The audio from the receiver is fed into a PC and software such as FLDIGI is used to decode it.

FSK data:

During the \$50SAT program loop 4 different types of packets are sent by the RFM22B. They are a ready packet, an acknowledge packet, a data packet and a FEC encoded data packet. To improve reliability of communications both data packets are sent 3 times. Although the packets are sent in FSK mode, they will be heard as noise on a FM receiver. The ready packet is sent once and the acknowledge packet is sent twice. The acknowledge packet is sent on receipt of a valid command packet (see later).

All packets have the same basic format, with only the amount of data payload varying. The transmission format is;

Frequency, 437.505Mhz

FSK deviation 5kHz

Data rate 1kbps

GFSK Modulation

Data sent MSB first

FEC data with FEC:

The FEC telemetry, prior to forward error correction, consists of 24 bytes. The first 21 bytes are a duplicate of the info packet packet data from flags up to and including Batvolts. This is followed by a 16 bit CRC (CRC-16) and a terminator byte (11, or 0x0b). This is then forward error corrected using a $r=1/2$, $L=4$, non-recursive convolutional encoder. The output of the encoder, which consists of 2 bits for each bit of data input, is then run through a 4 by 4 matrix interleaver. Since the FEC packet is almost twice as large as the info packet, it takes nearly twice as long to transmit. While it is still possible to successfully receive info packets on the ground, the FEC packets were added to improve the probability of successful reception telemetry data. In theory, the coding gain for this forward error correction scheme approaches 4.8 dB; in practice, it will likely be about 3 dB. This forward error correction scheme is the same as the one developed by Keith Packard for use in the AltOS operating system. This, in turn, is based on the forward error correction scheme used on the TI CC1111 ISM band transceiver. TI Design Note DN504 provides an excellent explanation of this forward error correction scheme, with an emphasis on the encoder, while TI Design Note DN507 describes the implementation of the decoder, which is based on the Viterbi algorithm.

Command uplink:

It is a requirement to be able to turn off the satellite transmissions if requested. For a 10 second period in every program loop (approx once a minute at full battery charge) and just after the slow Morse call sign transmission, the transceiver is in listen mode for 10 seconds, waiting for an incoming data packet. At the start of the listen period a ready packet is also sent. The separate ground station transceiver PCB and software is used to transmit the various command uplink packets that \$50SAT will accept. The 100mW output of the RFM22B will need to be suitably amplified up to 10W or more to allow \$50SAT to receive the packets in low earth orbit. There are three open commands that any licensed ham can use to get a report from the satellite:

Packet number 35 Test packet, when received \$50SAT transmits the received signal level (RSSI) as slow FM Morse numbers.

Packet Number 50 \$50SAT transmits the data telemetry info packet.

Packet Number 52 \$50SAT transmits the FSK RTTY data.

Experiments:

SEU experiment:

During the early development, there was concern that the non radiation hardened RAM in the PICaxe would be subject to Single Event Upset (SEU) corruption. To test for this, a large chunk of memory was filled with AA,55 checked at every program loop. If errors were detected they would increment an error counter which is reported by telemetry. Since launch, not a single SEU has been detected.

EEPROM experiment:

On startup, data is written from flash memory into an area of the EEPROM. Every program loop this data is checked for changes. The number of changes is sent with the telemetry. No EEPROM faults have been detected to date.

On orbit performance:

Telemetry:

The \$50sat team has been very fortunate to have attracted so many faithful listeners that have returned telemetry reports on a consistent basis from all over the world. Most of the telemetry is acquired using RTTY.

Battery performance:

One of the best surprises has been the exceptional performance of the battery. After going through 15 charge/discharge cycles per day for 9 months, the battery is still performing nominally. Michael has compiled a large data set in Excel format on the drop box¹⁴. There was one anomaly around the summer solstice where the battery was not receiving sufficient charge to maintain operation entirely through eclipse. Our best guess is that the orientation was such that the front or rear of the satellite was facing the sun during this time.

Things we wish we knew before launch:

Thermal environment:

The satellite tends to remain cold even when in the sun for a considerable amount of time. When coming out of eclipse, it takes about a quarter of the sun lit orbit time to warm to greater than 0 degrees C internally.

Stabilization:

If we spent more time understanding the dynamics and methods of stabilization we may have been able to reduce the spin fade and increase the solar panel sun exposure. This is one area where our lack of experience was evident.

Things we might have done different:

Cold power operation:

We don't directly measure the battery temperature. Temperature of the processor board and the RFM-22 radio are both reported and we assume that the battery would be approximately the same. When the temperature sensors are below 0 degrees C, the processor disables the output of the max power point trackers until the temperature rises above 0 C. Since the satellite takes considerable time to warm to the point of safe charging, the eclipse time is effectively extended. A better method would be to always allow solar voltage to be generated and disable the charge path to the battery when it is too cold to charge. This would reduce the power consumption from the battery while it is warming.

What can we do next:

There is always demand for more transponders. From what we have learned it may be possible to place a small, low power, low duty cycle transponder in a PocketQube. This could take the form of an APRS digipeater, a morse "robot" or possibly some sort of digital transponder. PocketQubes are very power limited and maybe trading bandwidth for power by using spread spectrum techniques would produce a practical transponder. \$50sat has proved that the PocketQube can be a viable form factor for low cost access to space.

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**PE0SAT LW2DTZ ST2NH DK3WN JA0CAW PE2G PY4ZBZ
VE3HEO LU4EOU WB2AOZ EU1XX N1AIA Kristaps
EA1JM Ozqube-1 IW0HLG VK2XV K8ETE KD8TBD G0EID
M5AKA ZA6AIC (via WebSDR)**

END NOTES:

1. http://www.hoperf.com/rf/fsk_module/RFM22B.htm
2. <https://www.sparkfun.com/products/10153>
3. <http://www.silabs.com/products/wireless/EZRadioPRO/Pages/si44303132.aspx>
4. <http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en546239>
5. <http://www.rev-ed.co.uk/>
6. <http://www.maximintegrated.com/en/products/power/supervisors-voltage-monitors-sequencers/MAX6369.html>
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10. <http://www.mouser.com/ProductDetail/Standex-Electronics/NDFEB-6X10MM/?qs=%2fha2pyFaduhc62ttKMbPbjf2Vq5gDFzyN8%252b87obQU9JjBy3hTU7dFQ%3d%3d>
11. <https://www.dropbox.com/s/31up5y3oyzoi53a/RFM22%20Range%20Tests%20September.pdf?dl=0>
12. <https://www.dropbox.com/s/fygz44x253w6489/50USDSat-BoxSat-Temperature-Tests-2012-10-03.pdf?dl=0>
13. https://www.dropbox.com/s/2d2x50z77r492md/%2450SAT%20-%20Eagle2%20-%20Communications%20-%20Release%20Version%20V1_2.pdf?dl=0
14. <https://www.dropbox.com/sh/l3919wtfiyw2gf/AADn3Fy4cjfwO9Lkn3jeDUwQa/Telemetry-analysis?dl=0>

STEM Education at Shaftesbury High School—A Brief History

Robert Striemer (VE4SHS) and Adrian Deakin (VA4AMD)

Abstract

SHARP and SATS are extra-curricular Science, Technology, Engineering and Mathematics (STEM) projects at Shaftesbury High School in Winnipeg, Canada. Students involved in SHARP receive a STEM education as they design, build, test and fly aircraft including high altitude balloons (HAB's). The need to track the HABs in flight led us to the APRS (automatic packet reporting system) and amateur radio. This resulted in a need for student radio operators so SHARP began to work with the local amateur radio club to provide certification courses at the school. Twenty-four call signs have been issued to the students and staff at Shaftesbury in the past four years. This activity came to the attention of Stefan Wagener, a local member of AMSAT. Stefan made us aware of ARISS and suggested that Shaftesbury High School build an ARISS telebridge station. We agreed and the station was completed in August 2014. Students will use the station to "work" satellites and to acquire and process telemetry from high altitude balloons and satellites. SATS students will learn hands-on about radio communications and orbital mechanics. The authors will give a brief history of these two non-curricular projects, SHARP and SATS, and provide our perspective on the state of STEM education.

Amateur Radio Arrives

In 2009, the teacher librarianⁱ at our small public secondary school, challenged the science teachers including the authors to fly a high altitude balloon (HAB) to the stratosphere in order to take pictures of space as he'd seen on a YouTube video. After some online investigations, the authors decided it would be possible for our students to design and build a HAB payload that could record images of space from an extremely high altitude. As this kind of activity did not fit with provincial science curricula, the project had to take the form of a noon-hour and after-school activity. Our next step was to take the idea to the students. Would there be enough interest to justify the effort? Would students give up their spare time to fund raise, design, build, test and fly the balloon and payload to the edge of space? Absolutely! As it turned out, we had 30 students from grades 9 – 12 (ages 14-18) of all interests and abilities more than willing to take up the challenge.

Fundraising for the project began quickly. A writing team was formed to complete grant applications and write letters requesting financial support. Other teams were formed including imaging, science and electronics teams. The teams worked independently but we all gathered together once a week to coordinate the overall effort.

Initially the teachers were unsure of the best way to track a high altitude balloon. How would we get the camera back from space? We discovered that the most commonly used method, at least in North Americaⁱⁱ, and the method we chose, was to use an amateur radio system developed by Bob Bruninga (WB4APR) called APRS (Automatic Packet Reporting System). We would need an APRS beacon and one or more certified hams at the school to turn on the transmitter. This was the beginning of our ongoing amateur radio adventure. While our students set about acquiring knowledge, designing a payload, sourcing materials and writing letters to potential donors, some of us also took amateur radio classes on the weekends.

The Shaftesbury High Altitude Robotics Project

The project required a name. We soon started calling it SHARP for Shaftesbury High Altitude Robotics Project. SHARP is an extra-curricular activity. It runs every day over the lunch hour and sometimes after school and on weekends. The teachers decided from the outset that the students must, to the greatest extent possible, drive the project and do the hands-on work. The teachers would act as mentors and facilitators. The project survives only by the interest demonstrated by the students. Therefore, all members are motivated volunteers.

Back in 2009 we did not know that HAB flights were actually quite common. We were surprised when we found out there was a group in Winnipeg that had experience with HABs and APRS tracking called WinCube¹. In the summer of 2009, some of us attended a Space Camp for high school students put on by Dr. Withold Kinsner (VE4WK) of the University of Manitoba's Department of Electrical and Computer Engineering and a founding member of WinCube. Through the Manitoba Space Campⁱⁱⁱ, and also WARC (the Winnipeg Amateur Radio Club), SHARP made some valuable contacts but at this point none was more important than Alan Thoren (VE4YZ) who became our chief mentor. Alan also donated much hardware to SHARP including amateur radios, antennas and power supplies.

During the 2009-10 school year the teams were making progress. Money started coming in. Materials were purchased such as a soldering station, a weather balloon, plumbing supplies and a helium regulator for filling balloons. The payload team learned how to solder and make precise cuts in foam board insulation using a hot nichrome wire. Three of us became certified amateur radio operators. In the spring of 2010, SHARP purchased a Byonics APRS transmitter and a Garmin GPS-18 receiver for the HAB payload and a Kenwood TM-D710A dual band mobile transceiver and AVMaP GPS navigator for the chase car. Bruce Feaver (VE4BDF), a commercial pilot and former Shaftesbury student, provided us with a lesson in parachute design. Later, Bruce provided the 24 inch parachute itself. Bruce also became the Operation Manager. One task he took on was filing the HAB flight NOTAMs with NAV CANADA. Other hams helped in various ways.

The SHARP team was ready to fly its first high altitude balloon by October of 2010. Given the predicted winds aloft, we decided to field trip the SHARP team 220 kilometres northwest of Winnipeg and launch near a resort at Elkhorn Manitoba. The resort would be our base away from school. Twenty students and four teachers arrived at the lodge on October 21st and immediately set up a shop to prepare the payload for launch in the morning. The next day, SHARP-1,^{iv} a 1500 gram helium filled balloon, parachute and payload lifted off from the nearby Erickson aerodrome. The chase that followed was very exciting. The balloon reached an altitude of 107000 feet. Three and a half hours after launch the payload returned to the ground just outside the city of Winnipeg and just 18 km from our school. Our students opened the payload box together and they were overjoyed when they discovered the camera was still recording video.

The SHARP 1 payload was loaded into a car and we returned to the school. By the afternoon we were all watching the flight video projected onto a large screen.

Watching the video, we felt as if we were onboard the balloon. We saw the pre-launch activity. After the countdown, the ground started to pull away. Fields and trees, roads and lakes appeared and then shrank until it seemed we were looking at a large map. As the familiar sounds of the Earth slowly faded away, blue sky slowly changed to black. Eventually we saw the curvature of the Earth from an altitude of over 32 kilometres. We had arrived at our destination – space. Then the balloon burst and the payload tumbled down. The rotation rate increased at an alarming rate. The payload underwent a violent and chaotic period of free fall through the near vacuum of the stratosphere. The sound of rushing air was now heard along with a banging sound made by the beacon's antenna as it was whipped against the side of the payload. Slowly the attitude stabilized and the descent slowed. Finally, we swooped over a deserted field and landed. After some time, feet and legs appeared. Students excitedly gathered around their “spacecraft”. The payload



Figure 1. The success of SHARP 1 generated enthusiasm for amateur radio.

was opened. The camera was still recording.

There was joy, excitement and pride all around. A year of team work had paid off. The video was proof that we could reach space. The students immediately expressed their enthusiasm for more HAB flights. We were immediately hooked on ballooning and amateur radio.



Figure 2. Students prepare a rockoon (rocket-balloon) for GPS/Arduino controlled launch. Satellite tracking antennas are visible on the school roof.

The students felt they could take the technology much farther.

Their ambitions grew and so did the size and complexity of their payloads. Two more successful flights followed in years to come. SHARP 2 flew in 2011 and reached an altitude of over 126000 feet. It included several science experiments and temperature and radiation measurements were made. SHARP 3.1 followed in 2013 and reached 121000 feet. SHARP3.1 carried with it several experiments, Arduino microcontrollers and a small radio controlled aircraft.

Integrated Science, Technology, Engineering and Mathematics Education

I'm not sure that any of the teachers involved in SHARP were aware of integrated STEM (Science, Technology, Engineering and Mathematics) education back in 2009 and 2010. Like our students, we

were learning and just having fun. The teachers were impressed that creative problem solving occurred naturally during SHARP noon hours. As teachers, we appreciated the freedom of not having to follow a prescribed curriculum or having to evaluate student work in terms of achieving specific learning outcomes. Each student brought with them unique skills and knowledge to be tapped. Older students naturally mentored the younger ones and acted as role models. Team work was essential for success. When something didn't work, it was usually because of poor communication between teams.

SHARP represented what we started calling "authentic learning". Every education student learns about Bloom's Taxonomy which refers to the classification of the different learning objectives. Bloom's Taxonomy divides educational objectives into three domains: cognitive, affective, and psychomotor. Good teachers employ all three domains in their lessons. In SHARP, the student is largely in control of their own learning and the student will naturally employ the three domains as they work their way through a problem.

Our highly motivated students worked very hard on their SHARP projects without the reward of a school credit but most didn't care. They saw the benefits. They learned how to solder, learned how to program microcontrollers, they become certified radio operators and they demonstrated that they could solve difficult problems often by trial and error and persistence. SHARP students needed to communicate their findings and teach each other thus reinforcing their learning. Some of them used these skills and their HAB experiments to win science fair awards. Learning was clearly evident even if no pencil and paper tests were written.

After each flight, the SHARP team sets new goals for the next HAB mission. High altitude balloon flights are a yearly activity with launches typically taking place in late October or early November from western Manitoba. The launch location is selected so that the payload lands on the floodplain south and west of Winnipeg. By the fall of 2013, SHARP had successfully flown three HABs. One mission was aborted (SHARP 3) due to extremely bad weather. Each mission has been more ambitious than its predecessor with more science experiments, better engineering, larger balloons, more advanced payloads and improved procedures.

Besides using amateur radio for tracking and communications during operations, SHARP students do radio direction finding activities to help in locating payloads on the ground. "Home-brew" directional antennas have been built. Certified students can borrow SHARP transceivers. However, they are strongly encouraged

to buy their own Baofeng UV-5r^v hand-held transceivers because their on-air skills progress much more rapidly when they have their own radio. Arduino microcontrollers are an important feature of the HAB payloads. SHARP students can take an occasional noon hour Arduino microcontroller class. Senior



Figure 3. The SHARP 3.1 radio controlled aircraft high above Manitoba.

students are used as instructors. Students also practice their radio controlled aircraft flying skills behind the school and in the school gym when winter weather prevents flying outside.

Fundraising and promotion of the program is ongoing. We have been the beneficiaries of outreach programs but SHARP students also do outreach. Our students have made numerous presentations especially to elementary schools. They have been invited to several special events because of their amateur radio and aerospace activities. Whenever the students attend these events, valuable eyeball QSOs are made. Recently, SHARP received an Iridium satellite data transceiver after a student approached a Solara Remote Data Delivery representative while we were attending an aerospace trade fair. The transmitter even came with the offer of free technical support!

The Amateur Radio Community

SHARP has increasingly become involved with the local amateur radio community primarily through the Winnipeg Amateur Radio Club. WARC has supported SHARP in many ways. WARC and RAC (Radio Amateurs of Canada) are among our biggest donors too. SHARP teachers will strive to introduce more of our students to WARC and its many activities as well as the Manitoba Repeater Society and Winnipeg



Figure 4. The Shaftesbury amateur radio team, September 2014.

ARES. Engineering students of UMARS (University of Manitoba Amateur Radio Society) track our HAB flights using their satellite tracking station (VE4UM) and their APRS i-gate. Some UMARS students are SHARP alumni and some UMARS members have come to the school to deliver Arduino microcontroller lessons as part of their outreach program. There have been at least two dozen local hams that have made contributions to SHARP over the years.

AMSAT and the Shaftesbury ARISS Telebridge Service

During the spring of 2013 we received a call from Alan Thoren to tell us that a friend of his would like to meet our team and possibly mentor our students. Stefan Wagener (VE4SW), a long time AMSAT member and the current Canadian ARISS delegate, came to the school during a lunch hour one sunny day in May. The students were outside testing a GPS controlled payload release circuit hanging below a small balloon. Stefan introduced himself and chatted with us for a while. He then visited the SHARP workshop and ham shack. Later he proposed the idea of building an ARISS telebridge station at the school. Of course we did not know anything about ARISS or what a telebridge was. Stefan patiently

worked with us and it wasn't long before we were very excited by the possibility of our student hams facilitating astronaut contacts with schools around the world^{vi}.

A steering committee^{vii} was assembled to guide the ARISS telebridge project. The committee included Mr. Stan Wiebe, the school principal. The project came to be known as SATS for Shaftesbury ARISS Telebridge Service. A budget was put together and a fund raising campaign started in the summer of 2013. A station call sign (VE4ISS) and a web domain name (ve4iss.ca) were obtained^{viii}. A list of equipment^{ix} was put together by Stefan and an overall plan for the classroom/satellite tracking station took shape. Soon we were stripping the interior of the old SHARP workshop. The floor was fixed and the interior was painted. New workstations were built and installed. The team assembled two



Figure 5. Assembling the HamTV antenna.



Figure 6. The ARISS telebridge ISS tracking antennas on the school roof.

20 foot long directional antennas and the HamTV dish antenna during the long winter of 2013-14. Spring came late, but by May 2014 the antenna systems were in place on the roof of the school. Finally, two Kenwood TS-2000 transceivers were donated by Prairie Mobile Communications (Winnipeg) and Kenwood Canada. The antennas were connected to what we now call the SATS ground station by the end of June.

The authors were really in over their heads on this project. Stefan exhibited considerable patience with our mistakes and the slow pace of progress. Snow on the roof was an issue into April this year. There is necessarily some bureaucratic red tape in dealing with the larger entity of the school division especially with respect to workplace safety, purchasing and information technology. One of the antenna rotors was giving us trouble requiring its removal from the roof on two occasions. That rotor has now been replaced. The twenty foot long, 2-metre antenna will oscillate slightly in the wind. We have had to do several realignments and tightening of brackets because of strong winds just in the first few months. Torque specifications for antenna mounting bolts still need to be worked out to stop movement and to prevent damage to the fiberglass boom supporting the antennas. As of September 2014, construction of the Shaftesbury ARISS Telebridge station is complete. The teachers and students still need to be brought up to speed on the station's operation but we expect that soon we will be ready for work and hopefully approved for ARISS contacts.

Secondary School Space Science Curricula

Mainstream science curricula across North America will likely include such topics as space exploration in the middle grades and universal gravitation, uniform circular motion and Kepler's Laws in physics programs. In the astronomy and space exploration unit^x, our grade 9 (senior 1) students make cardboard astrolabes. When used with a compass, they can measure the elevation and azimuth of celestial objects^{xi}. The North Star will always be found at an altitude of 50 degrees in Winnipeg (our latitude). The position of the other stars varies according to the time of day. Many hams will use a similar method to determine the elevation of their hand held directional antennas when working satellites. We look forward to seeing our students attempt to work satellites with their home-brew directional antennas.

An advantage of working with a satellite, as opposed to measuring the position of a star, is that it can be done at school during the day regardless of cloud cover. A notebook computer running SatPC32 or similar software would be a big help in predicting the satellite's pass and important for the teacher planning the lesson. An extension activity could involve the use of a satellite tracking system such as the WRAPS^{xii} or similar rotator system. By attaching a green laser pointer to a WRAPS rotor or satellite rotor simulator^{xiii} it should be possible to mark the passing satellite in the night sky, aiding students in pointing their directional antennas. Stellarium^{xiv} is a free planetarium program that can be used to point a telescope much like SatPC32 is used to point an antenna. Stellarium might be used with a WRAPS or rotor simulator to mark a star with a laser or point a small scope^{xv} or camera. A rotator like WRAPS that helps in viewing celestial objects as well as working satellites could increase its acceptance by astronomy teachers.

Universal gravitation is a topic studied by our grade 11 physics students. When combined with the topic of uniform circular motion in grade 12, Kepler's Laws are confirmed. Only circular orbits are considered mathematically. The table below shows the space related learning outcomes in the Manitoba Physics Curriculum for the grade 12 (senior 4)^{xvi}. Other North American physics curricula would be similar.

TOPIC 2.1: EXPLORATION OF SPACE
S4P-2-1 Identify and analyze issues pertaining to space exploration. Examples: scale of the universe, technological advancement, promotion of global co-operation, social and economic benefits, and allocation of resources shifted away from other pursuits, possibility of disaster
S4P-2-2 Describe planetary motion using Kepler's three laws. Examples: relate Kepler's Third Law to objects other than planets, such as comets, satellites, and spacecraft
S4P-2-3 Outline Newton's Law of Universal Gravitation and solve problems using $F_g = \frac{GMm}{r^2}$
S4P-2-4 State the gravitational potential energy as the area under the force-separation curve and solve problems using $E = \frac{-GMm}{r}$
S4P-2-5 Solve problems for the escape velocity of a spacecraft. Include: Law of Conservation of Energy, binding energy
TOPIC 2.2: LOW EARTH ORBIT
S4P-2-6 Compare the Law of Universal Gravitation with the weight (mg) of an object at various distances from the surface of the Earth and describe the gravitational field as $g = \frac{GM}{r^2}$

S4P-2-7 Outline Newton’s thought experiment regarding how an artificial satellite can be made to orbit the earth.
S4P-2-8 Use the Law of Universal Gravitation and circular motion to calculate the characteristics of the motion of a satellite. Include: orbital period, speed, altitude above a planetary surface, mass of the central body, and the location of geosynchronous satellites
S4P-2-12 Describe qualitatively some of the technological challenges to exploring deep space. <i>Examples: communication, flyby and the “slingshot” effect, Hohmann Transfer orbits (least-energy orbits)</i>

Learning outcome 2-8 above involves orbital properties such as speed, period and altitude which can be readily visualized with the help of software such as SatPC32. Few teachers would be aware of this tool unless a radio amateur who works satellites shows it to them. We use SatPC32 in the Shaftesbury ARISS telebridge station. Science teachers at Shaftesbury can take students into the ground station and show them satellite orbits on large computer monitors. Questions like “why are the orbits displaced westward with each pass” or “why is the footprint of one satellite bigger than another” naturally arise. The questions can be easily related to the rotation of the Earth and the satellite’s altitude, speed and period. Students can use the satellite orbital parameters on the monitors to determine other parameters using their physics knowledge (e.g. Calculate the mass of the Earth from the radius of the ISS’s orbit and its period). All students love computer games. Kerbal Space Program^{xvii} (KSP) is a very popular space flight simulator which has even caught the eye of JPL software engineers^{xviii}. We encourage Shaftesbury students from grades 9 to 12 to play KSP because of its realistic simulation of orbital mechanics.

A Perspective on STEM Education

The STEM model is based on the idea of engaging students in the four specific disciplines of science, technology, engineering and mathematics using an interdisciplinary and applied approach. The goal of STEM education is to integrate the four disciplines using real-world applications. Our experience with the SHARP and SATS projects shows that this model is very effective.

In Canada, provincial governments are responsible for setting curriculum standards. In Manitoba there is currently no provincial STEM education legislation and no provincial STEM curriculum (Manitoba Education, 2014). STEM education in Manitoba is only implemented locally by a small number of educators in the form of extra-curricular activities. Despite this, enrolment in the Faculty of Engineering at the University of Manitoba— Manitoba’s only engineering faculty—continues to climb. In the fall of 2012, enrolment in the faculty increased by 15% (Danakas). In the United States, STEM education is a national priority according to the May 2013 report from the Committee on STEM Education National Science and Technology Council in their STEM Education 5-Year Strategic Action Plan (US Government, 2013). The need for educators to train our 21st century learners, so they may move beyond the age of information towards an era of innovation is great, in order to meet increasing global demands in STEM related fields. This is our goal as STEM teachers; to develop future scientists, technicians and engineers through programs like SHARP and SATS and to inspire other teachers to do the same.

To engage more teachers, the authors have begun to work with MAPT, the Manitoba Association of Physics Teachers. We want to collaborate. We hope to kick-start other HAB programs and demonstrate

how amateur radio is used to work satellites with low cost technology. We have asked teachers and students from other schools to join us in amateur radio certification classes. Shaftesbury High School will be hosting the annual general meeting of the MAPT this fall. This event will include a tour of the Shaftesbury ARISS telebridge station. We hope we can make a lasting impression so we can build a STEM school support network where amateur radio is the key to an exciting Manitoba space education program.

We think it will take some time before we see mandated STEM curricula being delivered in most schools. There is movement to replace standard laboratory courses in the sciences with more discovery or inquiry based courses. This was the approach taken by the College Board in developing their new Advanced Placement^{xix} courses in algebra physics. However, the key signs of mature STEM programming such as curriculum rollout and teacher training in-services are faint. This may not be such a bad thing for groups such as AMSAT that see amateur radio as having an important role to play in advancing space education. Amateur radio is starting from behind in terms of teacher recognition. Biotechnology, robotics and forensic science programs are popular and more established in schools and it seems, more likely to be included in future curricular STEM programs. Most teachers do not realize that space is accessible through amateur radio. In time, amateur radio may be recognised by educators and so make a significant contribution to space education in primary and secondary schools.

So, will there be a significant place for amateur radio in STEM education? That may depend on the effectiveness of groups like AMSAT and the ARRL. NSTA (National Science Teacher Association) conventions^{xx} are good places to reach science educators. Science and technology teachers need to be made aware of the potential of amateur radio and convinced that the benefit to their programs is worth the considerable investment of their time. The hands-on support of the local ham community is important too. Teachers willing to give amateur radio a try will face the hurdle of certification and a new technology learning curve. They will need some support. Local amateur radio clubs can provide the support. The clubs should be encouraged to reach out to teachers and demonstrate the educational potential of amateur radio as it pertains to the high interest area of space exploration. By providing certification courses to students in schools, the clubs can build their membership. We applaud AMSAT, the ARRL and RAC for the leadership they are providing through teacher and student education programs including ARISS, FUNcube and the FOX project.

Shaftesbury ARISS Telebridge Station Equipment

ARISS Primary Antennas		
	22-Element CP 2m Yagi Specs	42-Element CP 70cm Yagi Specs
Model	2MCP22	436CP42UG
Frequency Range	144 to 148 MHz	430 to 438 MHz
Gain	14.39 dBic	18.9 dBic
Front to Back	25 dB Typical	25 dB Typical
Elipticity	> 3 dB	1.5 dB Typical
Beam Width	38°	21° Circular
Feed Type	Folded Dipole	Folded Dipole
Feed Impedance	50 Ohms Unbalanced	50 Ohms Unbalanced
Max VSWR	1.4:1	1.5:1
ARISS Secondary Antennas	Rotors/Cables	Radios & Additional Antennas
• 2 Gulf Alfa Dual Band 2m/70cm satellite yagis (phased for 2m & 70cm) • RF HamDesign HamTV 1.5m dish (Kuehne LNB downconverter)	• RF HamDesign 1x Spid RAS HR, MD-01 controller • RF HamDesign 1x Spid Big RAS HR, MD-01 controller • All LMR400/600 cables to station	• Kenwood TS-2000 & TS-2000X (primary & secondary radios) • Kenwood TM-D710A Mobile • Yaesu FT-8100 • Diamond 2m/70cm vertical • 2m Tape Measure Yagi • 2x ICOM V80 Handheld • 2x Baofeng UV5R Handheld
Software		TNC
• SatPC32 • Nova for Windows • Orbitron	• UISS • DireWolf • FL-digi / FL-digi HAB	• 2 Signalink USB • 2 Kenwood PC-1A Phonepatch

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Endnotes

ⁱ Our teacher-librarian at this time was Michael Friesen. Mike is a space enthusiast. He now teaches at Fort Richmond Collegiate in Winnipeg.

ⁱⁱ Airborne amateur radio APRS is not lawful in the UK. However there is a great deal of HAB activity there including school activity. The UK High Altitude Society (UKHAS) employs a worldwide volunteer network of hams for tracking HABs that has served well.

ⁱⁱⁱ SHARP still contributes students each summer to the University of Manitoba Space Camp.

iv SHARP 1 Mission Goals:

1. To launch a scientific research payload on a High Altitude weather Balloon (HAB)
2. To track the payload using the amateur radio APRS - Automatic Packet Reporting System
3. To recover the HAB and its video camcorder
4. To record images of the curvature of the Earth and of outer space
5. To obtain flight data including altitude, airspeed (wind velocity), latitude and longitude
6. To report the findings of the mission

^v Baofeng UV-5r dual band HTs can be purchased in bulk for less than \$40 each.

^{vi} Students at Sacred Hearts Academy a K-12 school in Honolulu, Hawaii have operated an ARISS telebridge station since 2000 and supported SAREX before then.

^{vii} The steering committee consisted of Stefan Wagener, Stan Wiebe (our very supportive principal at Shaftesbury High School), Derek Boutang (Pembina Trails School Division Director of Information Technology) as well as the authors.

^{viii} Ve4iss.ca is reserved. We have not yet begun to develop this web site. Our current site address is <http://shsballoonproject.pbworks.com>. We have a Twitter presence at <https://twitter.com/rjstriemer> and photos are stored on flickr.

^{ix} The hardware list included three computers (Windows 7 / SatPC32), six monitors, two wall mounted 50 inch monitors, two uninterruptable power supplies, two RF HamDesign rotors and M² Antenna Systems directional antennas and eight foot towers, pre-amplifiers and amplifiers (donated by the Winnipeg Amateur Radio Club), Tigertronics TNCs, Signalink soundcards, polarity switches, antenna switches and coax cable, grounding rods and a grounding bar. Two new Kenwood TS-2000 transceivers were very kindly donated by Prairie Mobile Communications (Winnipeg) and Kenwood Canada.

^x http://www.edu.gov.mb.ca/k12/cur/science/outcomes/s1/topic_charts.pdf

^{xi} S1-4-01 Use a coordinate system to locate visible celestial objects, and construct an astrolabe to determine the position of these objects. Include: altitude, azimuth.

S1-4-02 Observe the motion of visible celestial objects and organize collected data.

Examples: graph sunrise and sunset data, track the position of the Moon and planets over time.

S1-4-09 Explain how various technologies have extended our ability to explore and understand space.

Examples: robotics, Canadarm, Hubble telescope, Lunar Rover, space station, Sojourner Rover, Pathfinder and Galileo space probes...

^{xii} <http://ww2.amsat.org/xtra/wraps-mark-spencer-wa8sme-gst-jan-2014-copyright-arrrl.pdf>

^{xiii} <http://www.arrrl.org/files/file/ETP/Antenna%20Rotor%20Simulator/Article.pdf>

^{xiv} [http://en.wikipedia.org/wiki/Stellarium_\(computer_program\)](http://en.wikipedia.org/wiki/Stellarium_(computer_program))

^{xv} <http://simonbox.info/index.php/astronomy>

^{xvi} <http://www.edu.gov.mb.ca/k12/cur/science/found/physics40s/index.html>

^{xvii} http://en.wikipedia.org/wiki/Kerbal_Space_Program#Physics

^{xviii} <https://web.archive.org/web/20131227041757/http://www.penny-arcade.com/report/article/nasas-jet-propulsion-lab-is-obsessed-with-a-certain-game-and-i-bet-you-can->

^{xix} http://apcentral.collegeboard.com/apc/public/courses/teachers_corner/224794.html

^{xx} <http://www.nsta.org/conferences/>



VT-HUME Education Initiative for Academic Year 2015 (and our hoped for collaboration with AMSAT!)

**Dr. Robert W. McGwier N4HY, Dr. Kira Gantt, Zach Leffke KJ4QLP, and
Sonya Rowe KK4NLO**

We are developing a program that combines the building of cube satellites (CUBESAT), at first in collaboration with AMSAT as well as the University of Illinois, and then on our own, but always with an extensive K-12 educational outreach. The goal of our effort is: 1) to educate K-12 students in mathematics and satellite technology, 2) to promote the field of Spacecraft Engineering, 3) to promote a partnership between AMSAT, ARRL, and Hume/Space@VT for the purposes of first local and then national educational initiatives, 4) to launch CUBESAT in support to AMSAT and finally an independently developed satellite with the direct input of local high school students that communicates functional experimental data that can be used in the classroom, and finally to aid in achieving independent space-faring status with our own smallsat designed, built, tested, and controlled at VT (we will still need someone to launch us!).

Background

Dedicated to its motto, *Ut Prosim* (That I May Serve), Virginia Tech takes a hands-on, engaging approach to education, preparing scholars to be leaders in their fields and communities. As the commonwealth's most comprehensive university and its leading research institution, Virginia Tech offers 215 undergraduate and graduate degree programs to more than 30,000 students and manages a research portfolio of \$450 million. The university fulfills its land-grant mission of transforming knowledge to practice through technological leadership and by fueling economic growth and job creation locally, regionally, throughout Virginia, and across the nation. Virginia Tech is located in Blacksburg, Virginia and maintains a large presence in the National Capital Region (NCR). Virginia Tech NCR is located in Arlington, VA blocks away from ONR, AROSR, DARPA, and NSF that collectively invest ~\$13B/yr. in research. Virginia Tech performs applied research and development leveraging the combination of a rich multi-disciplinary research enterprise at the University and its positioning in the National Capital Region at the nexus of the national security/technology ecosystem.

THE HUME CENTER

The Hume Center for National Security and Technology at Virginia Tech leads the university's classified and restricted (ITAR, proprietary) research portfolio in signals intelligence (SIGINT), electronic warfare (EW), and command control communications computers intelligence surveillance reconnaissance (C4ISR) and now Aerospace Systems. The Hume Center's core team consists of 30 researchers and 25 graduate students, with access to technology-focused academic departments and centers through its network of affiliated faculty and students. The

Invent the Future

Hume Center has a dedicated staff of research faculty, Members of the Technical Staff (MTS), drawn from all over the defense and intelligence sector, including the DoD, NSA, national labs, and defense contractors, that have acquired hands-on experience and insight into the operational needs of our defense and intelligence community. It is currently a \$10M a year research center and is growing rapidly. We award over \$1,000,000 a year in scholarships and support many graduate research assistants and undergraduate researchers. We have 120 undergraduates in our programs and 57 graduate students.

AEROSPACE SYSTEMS

Space @ VT and the Hume Center jointly collaborate on multiple projects to improve satellite communications (SATCOM) and develop new CUBESAT hardware for the USG and other agencies that reduces the O&M cost of satellite deployments while allowing a drastically reduced technical refresh rate. That program is under development at the National Reconnaissance Office and will be completely unclassified CUBESATS. Virginia Tech has three NASA ELaNa launches by itself or with its partners such as AMSAT. Virginia Tech recently hired Dr. Jon Black from AFIT and NRO as an Associate Professor of Aerospace and Oceanic Engineering and the Hume Center has named him its Associate Director of Research for Aerospace Systems.

THE HUME SPACE PROGRAM

With \$92,000 of funding from the Virginia Tech College of Engineering, the Hume Center is building a satellite ground station in concert with Space@VT. This level of funding would seem small in a world where contractors do all the work. In our case, this is just the equipment budget. The labor costs are not included in this number and all the labor will be done by students in concert with Virginia Tech and Hume faculty, including some members of technical staff that many in AMSAT already know and one of the co-authors. Zach Leffke is the Principal Investigator on this design and construction and Sonya Rowe is our Project Manager. This will enable Hume to conduct a wide range of real-world experiments and the funding received was accompanied by terms and conditions that require us to directly impact undergraduate and graduate engineering. One such experiment will include the first direct communication with an S band SDR on board the International Space Station (ISS), the project is known as the NASA Scan Testbed, which is a host payload for space-based experimentation. In such a scenario, VT's ground control room will be hosted in Space@VT and the ground station and antennas will be remotely configured per Hume personnel design.

The Hume Center has multiple contracts with the National Reconnaissance Office and while we are not allowed to say specifically what we do for NRO, it is common knowledge what NRO does, though we may not confirm it.

The Hume Center will be awarded a contract from a commercial entity, to manage and control a smallsat spacecraft expected to be launched into low earth orbit in 2015. The infrastructure made possible by the funding seems to already be increasing Hume's capacity to conduct real world experiments in space, and significantly impact student education through unique experience. In

addition, this ground station will provide support for the international QB50 project. Dr. McGwier, Director of Research, Zach Leffke, Member of Technical Staff, and Sonya Rowe, Project Manager direct and support construction of the ground station and the effort to support QB50. Dr. Jon Black will be the principal investigator on the contract with the commercial entity.

The Hume Center has an existing relationship with the National Reconnaissance Office in Chantilly, VA. NRO is planning to launch educational activities of its own aimed at training young system engineers and contract management personnel through the use of CUBESAT and small satellite experiments. This new program will be used to train new and inexperienced NRO personnel by having them run \$8,000,000 small satellite design, construction, build, and operate projects. The Hume Center will play a role in this project with or for NRO which is to be determined.

HUME EDUCATIONAL PROGRAMS

The Hume Center's educational programs provide opportunities for hundreds of students per year to be engaged in national security programs. These activities are funded through the Hume endowment and educational grants, such as the current Intelligence Community Center for Academic Excellence, the NSF CyberCorps Scholarship for Service program and our Academic Affiliates Program. The educational office of Hume disperses scholarships, provides counseling for undergraduates and graduate students going into national security fields, and conducts extensive outreach activities to increase the talent, diversity, and quantity of the talent pipeline coming into the institution. Kira Gantt, Educational Program Manager, with support from others is responsible for the educational programs of the Hume Center.

Approach-

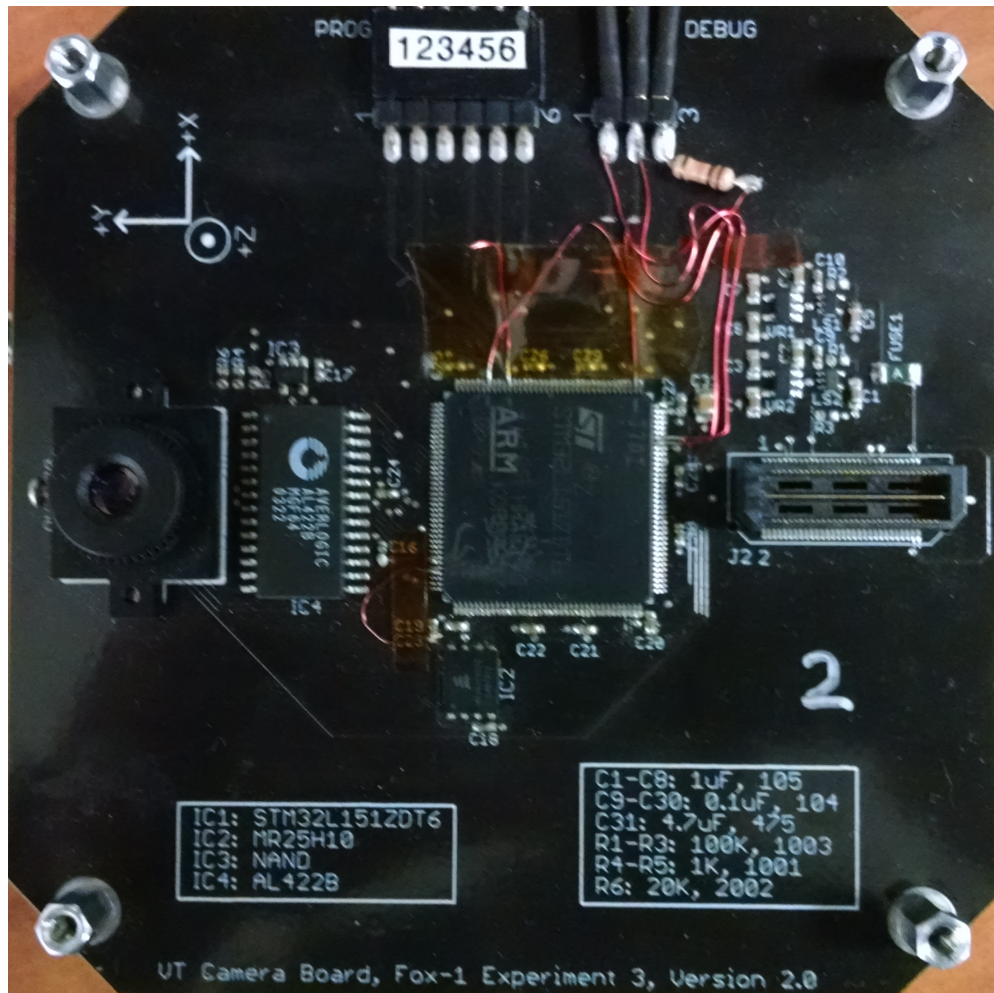
The VT-HUME CUBESAT program will consist of four major channels of activity that are being developed concurrently (Figure 1, see attached).

Education- In partnership with local schools in Montgomery County (TBD), Roanoke County (high school and elementary), Pulaski County (middle and high school), and Roanoke City (middle and elementary) we are developing lesson plans that teach math and satellite technology lessons but also adhere to Virginia's Standards of Learning (SOLs). These plans are being developed with teachers at these schools to increase stakeholder buy-in. Contacts in these schools have already been identified in most of these schools by the Hume Center Education Manager. The Governor's School in Pulaski County and Governor's STEM Academy in Roanoke County will participate in both assembling and programming the satellite and components. We are seeking support to send 6 teachers to the ARRL Teacher Institute. Small mobile ground stations will be built by Hume researcher Zach Leffke and donated to the schools for the newly minted amateur radio operators/teachers to use to receive telemetry from the Fox-1 series satellites after launch. Students receiving this data will be

able to perform various analyses- for example: attitude determination and Doppler shift. The mathematical calculations necessary to convert and analyze this data will be part of the lesson plans that are developed. The addition of a camera to the Fox-1 series will allow students to download pictures and learn applicable lessons in geography and potentially meteorology.

Goal- The objective is to educate students in Mathematics and Engineering. Our choice of schools has been carefully considered to reach as many talented students as possible with particular attention being paid to reaching students who might not otherwise get this kind of exposure. We expect that the lesson plans developed will add to those already developed by ARRL and can be used nationally.

Experiments- The Fox-1 Series spacecraft is being used as a template for the Hume CUBESAT. A spacecraft bus will be developed (or duplicated from the AMSAT Fox Series) with the intent to have the students design and build the experimental payloads. One such payload that is planned to be carried by this spacecraft is the 640x480 pixel CMOS camera experiment being designed and built by VT for the AMSAT Fox-1 series spacecraft. This camera experiment takes a digital image, compresses the data using JPEG compression routines, and then then downloads the image via a high rate downlink. A picture of one of the prototype cameras is shown below.



In addition to this, one experiment for the students will develop is a MEMS gyro experiment similar to that which is already onboard the Fox-1a IHU. The difference from the Fox-1a sensors is that this experiment will log whole orbit data, to be downloaded by the students as part of the curricula. Finally, the standard state of health information will be available to the students as well (such as solar panel voltages, battery voltages, spacecraft temperatures, etc.).

An important note is that the curricula will not simply be to have the students download data from a cubesat and call the experiment complete. An important goal of this project is to develop curricula that makes use of the downloaded data and incorporate it into usable lesson plans. The students will take information and actually analyze the real-world data to reach some sort of engineering conclusion. This can be accomplished in the near term by focusing on the AMSAT Fox series spacecraft. Longer term, the curricula can be expanded to include the data available from the Hume CUBESAT (such as the whole orbit MEMS gyro data).

Goal- The students will download data that includes the whole orbit MEMS gyro data that contains information concerning the attitude of the spacecraft. In addition to this information, the students will also have telemetry that includes solar panel voltages. Finally, the students will

have JPEG images taken by the camera. The fusion of the MEMS gyro data, the solar panel voltage data, and the JPEG images, through curriculum lead by the teachers, will allow the students to answer questions such as “Which face of the spacecraft is most directly facing the sun?” The students will be asked to guess which face of the spacecraft will be facing the sun during *tomorrow’s pass*. The students will then be able to go out, download more data, and see who analyzed correctly.

Communication- As the program starts we will make sure that materials are prepared to promote our efforts and inform the communities of Virginia Tech, AMSAT, and ARRL. As time progresses we will prepare a technical manuscript of the project and with a description of the educational efforts for publication within the community. This will alleviate some of the issues with ITAR regulations surrounding this work. We will also promote our efforts to the local community through local media as well as inform Virginia state legislators through contacts developed by the Hume Outreach office. Finally, we will present this material on a national level at relevant meetings as well as national media.

Goal- The objective is to publicize and inform various stakeholder groups and communities of our efforts. This will be important for sustained funding as well as recruiting new students to both RF engineering as well as the amateur radio community.

CUBESAT- As the development of curricula based on the experiments loaded onto the Fox-1 series is completed, a CUBESAT will be built with student involvement. We will build a satellite at Space@VT with help from chosen high school students from participating programs as well as undergraduates, graduate students, and the thing we feel many CUBESAT’s lack: permanent members of our technical staff to maintain corporate memory and the experience base to make this work long term. This process, we hope, will be a perfect venue to teach these advanced students from the Governor’s School and STEM Academy to learn about launch and satellite principles and in cooperation with faculty members at these schools with direct support to their lesson planning as a new and hopefully exciting resource. They will also have the opportunity to fabricate, build, and program payloads that are contained within the CUBESAT under Hume and Space@VT supervision. A berth on a SpaceX flight for a later Fox 1 (Q3 2015), has been tentatively confirmed through the collaboration with AMSAT. We intend to provide not only a camera but a whole orbit data collection capability. The data that is sent from the CUBESAT will be used for the educational principles outlined above.

Goal- The objective is two-fold. 1) Assembling a functioning CUBESAT *with* student involvement. 2) Having the students incorporated into the process will give them a much greater appreciating and stake in the concepts they are learning about.

Personnel-

Dr. Robert McGwier is the Director of Research of the Ted and Karyn Hume Center for National Security and Technology, and Research Professor in the Bradley Department of Electrical and Computer Engineering at Virginia Tech. He leads the overall execution of the Center's research mission, Blacksburg operations, and leads the university's program development efforts in national security applications of wireless and space systems. His area of expertise is in RF communications, digital signal processing, and satellite systems/communications.

Before joining Virginia Tech, Dr. McGwier spent 26 years as a member of the technical staff at the Institute for Defense Analyses' Center for Communications Research in Princeton, NJ, where he worked on advanced research topics in mathematics and communications supporting the Research Directorate of the National Security Agency and other members of the IC. He received his Ph.D. in applied mathematics from Brown University in 1988. His work on behalf of the federal government has earned him many awards, including the *Intelligence Community Seal Medallion* given in 2002 by DCI George Tenet.

Dr. McGwier is an avid amateur radio operator (call sign N4HY) and has previously served as the Vice President of Engineering for the Amateur Radio Satellite Corporation as well as on the membership on its board of directors. He is a member and former director of the Tucson Amateur Packet Radio. He won the Dayton Amateur Radio Association Technical Award in 1990 for his work on behalf of AMSAT, TAPR, and amateur radio in general. He received the Central State VHF Society Chambers Award in 2007 for his work in software defined radio and its application to amateur radio.

Dr. Jon Black, Associate Professor of Aerospace and Oceanic Engineering, is Associate Director of Research for Aerospace Systems, a member of the Center for Space Science and Engineering Research (Space@VT), and an Affiliate of the Ted and Karyn Hume Center for National Security and Technology. Prior to joining VT, Dr. Black served as a faculty member in the Aeronautics and Astronautics department at the Air Force Institute of Technology (AFIT), Wright-Patterson Air Force Base, Ohio. There he was the founding Director of the Center for Space Research and Assurance. As Director, Dr. Black focused on the center's efforts on the execution of cutting-edge space technology development and scientific space experiments; managed and executed the annual \$2 million center research portfolio; supervised a diverse group of 20 consisting of research faculty, program managers, laboratory and administrative staff, graduate students, and summer interns; briefed senior Department of Defense and Intelligence Community leadership advising national strategy; and cultivated research and educational relationships inside and outside AFIT. He served as PI or Co-PI on five spaceflight experiments.

Zach Leffke, Member of Technical Staff. Mr. Leffke is a recent graduate from the VT Bradley Department of Electrical and Computer Engineering where he earned both his BSEE and MSEE degrees. During his time as a graduate student, Mr. Leffke worked as a Graduate Research Assistant on multiple Hume Center contracts. Mr. Leffke's Master's Thesis topic was focused on the design of a distributed network of ground station receiver nodes with the goal of increasing access time to cubesats in LEO. Prior returning to Virginia Tech to complete his

BSEE and MSEE, Mr. Leffke was a Satellite Communications Operator in the United States Marine Corps. As a Corporal of Marines (E-4), Mr. Leffke served as a Satellite Team Leader and the Maintenance Non-Commissioned Officer (NCO) for 7th Comm Bn., B Co., Satellite Platoon out of Okinawa, Japan. As a Sergeant of Marines (E-5), Mr. Leffke served as the Ground Mobile Forces Satellite Communications Chief for the Joint Task Force Enabler Platoon of the 22nd Marine Expeditionary Unit out of Camp Lejeune, North Carolina. His amateur radio call sign is KJ4QLP.

Dr. Kira Gantt, PhD, is the Education Program Manager for the Hume Center. She maintains the day to day management of the ICCAE, SFS- Cybercorps, Hume Scholarship and Educational Outreach Programs. She acts as liaison between the Hume Center and the participation schools as well as helps develop to lesson plans. Dr. Gantt has over 13 years of experience in academic environments and has been involved in educational programming for scientific professionals for 6 years. She is an experienced researched with an extensive publication record in previous fields.

Sonya Rowe is a Project Manager with the Ted and Karyn Hume Center for National Security and Technology within the Institute for Critical Technology and Applied Sciences at the Virginia Polytechnic Institute and State University. She supports sponsored research programs for the Department of Defense and Intelligence Community. Prior to joining the Hume Center, Sonya spent six years with the U.S. Department of State, Bureau of Diplomatic Security during which time she also received her Master of Science Degree in Strategic Intelligence from the National Defense Intelligence College. She is a Certified Associate in Project Management, speaks fluent French and volunteers with the Virginia Wounded Warrior Program. Her amateur radio call sign is KK4NLO.

OLD SCHOOL !

A Backward Glance At AMSAT Education And Its Continued Relevance

**By E. Michael McCardel, KC8YLD
AMSAT V.P. Educational Relations**

ABSTRACT: Forty years ago AMSAT teamed up with the Talcott Mountain Science Center and the ARRL to produce a well-received educational curricula involving communications through OSCAR satellites. The program was a wildly successful in its day and would stand out as an exemplary program today. Many parallels can be drawn between this program and our current educational outreach, with ARISS, and our relationship with ARRL and NASA.

Education isn't just part of something AMSAT does. Education is part of who we are. When founded 45 years ago we were founded as an Educational Organization.

Our Mission Statement includes,

“AMSAT is a non-profit volunteer organization which designs, builds and operates experimental satellites and promotes space education. We work in partnership with government, industry, educational institutions and fellow amateur radio societies. We encourage technical and scientific innovation, and promote the training and development of skilled satellite and ground system designers and operators.”

Our current vision states

“Our Vision is to deploy satellite systems with the goal of providing wide area and continuous coverage. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups.”

In review of AMSAT's original purpose and objectives the word "Education" isn't specifically used, but rather the more encompassing term "Scientific" was used. However, it seems clear that "Scientific" refers to learning and discovering through experimentation, development of skills, advancement of specialized knowledge and to disseminate scientific and technical information which were derived from our communications and experimentation by "encouraging publication of this information in treatises, theses, technical journals or other public means."

Education is part of our earliest Mission Statements and Objectives. In the "AMSAT-OSCAR 7 Technical Operations Plan and Experimenters Guide" the Mission Objectives are clear, "The

principal objective of the AMSAT-OSCAR 7 mission is to provide a means for its use as an educational tool in schools. Other objectives include the demonstration, by means of stations in the amateur services, of the feasibility of using satellites with small user terminals for "bush" communication, emergency communication, communication between medical centers and isolated areas, aeronautical, maritime and land mobile communications. direct satellite-to-home voice broadcasting to simple amateur receivers and other similar applications. Further objectives are to demonstrate special operating techniques that enhance the usefulness of low orbits for these satellite applications and to test new communications repeaters and telemetry systems for operation with small terminal users. OSCAR 7 was and IS an experimental, educational satellite.

Educational Relations exists to engage and partner with educational institutions with the ultimate purpose of keeping Amateur Radio in Space. We believe that in developing cooperation among educational institutions and learning how AMSAT might assist with meeting their goals, we open avenues that will support our mission in the short term and in the long term. This has been working for us since before AMSAT was first organized.

March 9 of next year is the 50th anniversary of the launch of Oscar 3. It carried a receiver which monitored 100kHz of the 2-meter band. It also carried, onboard, beacon and telemetry transmitters. It was the first true amateur communications satellite. All told 98 participating stations in North America and Europe made 176 two-way contacts. There were hundreds of "heard" reports listed by over 1000 different amateur stations. The challenge inherent for its successful use moved many a ham to learn as much as possible about orbital mechanics. A true "teachable moment".

Oscar 5 was an international effort being designed and built by students at Melbourne University in Australia, its full name being Australis Oscar 5. It became the first satellite project carried through by, the then new, AMSAT. Launched in early 1970 it was an educational satellite designed to transmit only. Signals were radiated in both the 2 and 10 meter bands and allowed for studying ionospheric effects near the peak of a sunspot cycle. Also being tested were a seven-channel telemetry system and the magnetic attitude stabilization system as well as a 10 meter commandable beacon. Oscar 5 was the first amateur satellite to be used in extensive educational work by the Talcott Mountain Science Center of Avon, CT.

In fact Oscar 5 was the first amateur satellite to be commanded when Bill Dunkerley, WA2INB, using Talcott Mountain UHF Society's command station, was asked to turn it off and back on in a sort of reboot operation. At the time Bill was an AMSAT Director, he was also Managing Editor of QST at ARRL Headquarters, as well as the Director of the Talcott Mountain UHF Society and served on the Advisory Council of the Talcott Mountain Science Center. He was a strong advocate for using amateur radio satellite for in-class education and spearheaded the preparation of the OSCAR school curriculum material as well as the educational and training programs for OSCAR 6 and 7. Bill also wrote many articles for QST and the IEEE on the use of amateur radio satellites. Bill and the Talcott Mountain Science Center were pivotal in AMSAT's early educational outreach.

In anticipation of the Oscar 6 launch in 1972, the Talcott Mountain Science Center constructed and delivered three OSCAR terminals. These were designed for use with OSCAR 6 and future satellites in NASA's Spacemobiles, which visited schools and provided demonstrations pertaining to space. In addition AMSAT entered into a contract with the Talcott Mountain Space Center to prepare a workbook containing curricula based on the use of amateur satellites as tools in the classroom. The product, "Space Science INVOLVEMENT" was a 63 page curriculum supplement for classroom use of an active communications satellite. It was published by the ARRL in 1974. The Center, also offered fellowships to educators outside the US to learn how amateur satellites can be used in classroom instruction. The curricular supplement was reprinted in 1975 and plans were made for an updated second edition, but I don't believe a second edition ever surfaced. Interestingly enough the supplement is a working document. It is still viable for OSCAR 7, and can easily be adapted to the current and future fleets of amateur satellites. In fact links to the document were recently published by the UK's Funcube project as supplemental classroom material.

Copies of "Space Science INVOLVEMENT" can be downloaded in two parts at
<http://funcubeblog.files.wordpress.com/2010/11/space-science-involvement-1.pdf>
<http://funcubeblog.files.wordpress.com/2010/11/space-science-involvement-2.pdf>

Lesson content in the guide includes:

- What Keeps Satellites Up
- What Governs the Speed of a Satellite?
- Oscar Orbital Studies from Doppler Measurements
- Satellite Tracking and Orbital Mechanics
- Finding Oscar and Determining the Orbital Period
- Scientific and Mathematical Activities Involving OSCAR
- Scientific and Mathematical Activities Using Telemetry.

Its appendix includes:

- Useful Content, Formulae and Conversions
- Equipment Recommended for Classroom Use of OSCAR 6
- Transmitting Through OSCAR 6
- Satellite Systems
- Pre and Post Tests
- And Instructor Evaluation of the Guide

This treatise was freely available and distributed to all who asked for a copy.

I highly recommend it as a resource and encourage anyone, especially teachers, ARISS Mentors, and operators who frequently demonstrate to schools, at hamfest, clubs and other venues. I am discussing with the ARRL through Debra Johnson, K1DMJ, Education Services Manager for Amateur Radio Relay League, about reviving and updating the guide as a PDF file that can be easily downloaded for distribution and use. I have recently expanded this conversation to include Kira Gannt, Educational Program Manager for the Hume Center at Virginia Tech. Ideally

any update will include updated reference to common core and STEM objectives which are met with each activity.

Supplemental materials were also developed to go along with the Space Science Involvement booklet. AMSAT newsletters, glossy photo prints of OSCAR 7 were made available. John B. Meagher W2EHO of WABC News, New York produced an audio tape containing an actual OSCAR QSO (voice and cw) with a discussion of space communications. This was originally aired on WABC news and later released for duplication. ARRL made several copies and loaned them to interested educators. AMSAT produced 35 mm-colored slides of the construction of Oscar that were loaned under the direction of the ARRL. A half hour color videotape "Oscar and the Ham" featuring Jean Sheppard K2ORS and Dr. Owen Garriott W5LFL was produced at League request. It was shot on location at the Johnson Space Center and the Talcott Mountain Science Center by Connecticut Public TV for use on the PBS Network and in schools through audiovisual facilities. Post production assistance was provided by the PBS Amateur radio Club. The content depicted a two way OSCAR contact in a classroom setting and presented discussion on telemetry, ionosphere, equatorial and polar orbits, Faraday rotation, and the Doppler Effect. ARRL prepared material to assist amateurs in the role of presenting how to make an OSCAR contact. "Guideline for Radio Amateur Classroom Demonstrations - Oscar Satellites" contains information about special AMSAT bulletins, how to decode telemetry and what two way communication through OSCAR is like. Included with this was "Instructor Remarks, Space Science Demonstration - Planet Earth Laboratory and Amateur Radio Station". Prepared by the Hall of Science in New York it took the amateur by the hand, step by step, into discussions on inertia, the force of gravity, what keeps the OSCARs in orbit, satellites specifics including solar energy, signals and antenna.

Note that a team from AMSAT presented training during the ARRL Centennial Conference in Hartford that covered these same topics. Many of the same topics are also covered in Gould Smith's "Getting Started With Amateur Satellites." Further NASA provided their mailing list for the distribution of newsletters, promoting AMSAT's educational participation and the Talcott curriculum guide, to 35,000 science teachers

An interesting tidbit I uncovered in my research was that an early '70s AMSAT proposal to NASA for the inclusion of an amateur radio aboard Skylab was not approved. It was well received but, according to Bill Tynan, W3XO, the Skylab project had advanced too far to allow punching a new hole to accommodate an antenna. Regardless, the proposal seemed to plant a seed if not pave the way for Owen Garriott's first two way amateur radio contact from space in 1983. This is a good example of how outreach and relationship projects work. They build off of each other, even though they may not produce the outcomes originally hoped for. Frank Bauer and I found out first hand at the ISS Research and Development meeting this past July about how keeping communications open with parties interested in education reaps benefits. The ARISS program was near extinction, but we found life through old friends and new acquaintances.

There are many parallels that can be derived between the early Talcott Mount Curriculum and the early AMSAT education outreach and our current successes with SAREX and ARISS. The first, which is paramount to the success of both endeavors, is the relation and cooperation among the ARRL, AMSAT and NASA. Similarities can be seen between the Talcott initiative and today's ARRL programs including their Education, Technology Program (ETP) and the Teacher's Institute (TI). AMSAT's ability and willingness to reach out and engage with educational institutions, like the Talcott Mountain Science Center, set a precedent which continues to work for us today. Just as the success of ARISS is based on these same relationships so was the early and rather spectacular success of bringing the Talcott Mountain curriculum to the schools. Both, in their own way and time, engaged the teachers and youth of their day in space technology and served to inspire many to seek careers in Science, Math, Engineering and Technology by making space technology and communication relative. Many of the early Instructors' remarks about the Space Science Involvement curriculum parallel those we receive today about ARISS contacts. The AMSAT educational program goal of 1975 still rings true today.

"The goal in this program is primarily to present amateur radio to the public in a favorable, glamorous light, using the OSCAR satellites as a vehicle. NASA adds prestige and the educational channel is excellent for exposure efficiently and economically."

Here are a few of the early testimonials of teachers who used these early resources in the classroom:

"The in-the-classroom demonstration consisted of a one hour presentation explaining the principles of satellite communication including orbit structure, communication technique, and the Doppler shift. Slides provided by AMSAT were also shown. Later the group met for a demonstration at the instructor's home where they made contact with a couple of stations on Morse code. Transmitters, receivers, and antennas were discussed; also, between orbital passes an HF demonstration was held. As a result, several of those in attendance are now working on their Novice amateur radio licenses."
-- Jim Hermanek, Mitchell, SD HS

"Most of my students had never seen a communications receiver and had no conception of radio communications outside of what they had seen on television. All found that communications now had more meaning. The idea of actually being able to hear a satellite transmit, to plot its course, to interpret the telemetry was sufficient to motivate the students to learn more."
-- Michael Hopkins, Boston, MA

"The students are quite impressed with the idea of using man-made satellites to measure the mass of the earth. The height of OSCAR above the earth is 910 miles, and the period is about 115 minutes. Changing these data and solving the appropriate

formula yields the mass of the earth... The use of OSCAR has added interest that could not have been achieved by using only textbook data."

-- Eugene Roliff, Ravenna, OH HS

"...Robin Andrew, GM3WFJ, brought his receiver to our classroom and gave a short talk on OSCAR 6, followed by a demonstration on tape. We were unable to time his visit to coincide with a pass. A few days later some of my pupils had put up a crossed dipole for 29 MHz and were receiving OSCAR 6 for themselves, getting considerable excitement from knowing when it would pass next and at what inclination. At that stage they said their geography had benefited from having put a stiff wire circle around a globe to predict the satellite position. We are in a remote rural area where broadcast signals are difficult to receive, so OSCAR 6 and 7 are quite a source of interest to my pupils."

-- E.W.H. Jarvis Scotland

"Students at Belton Honea Path High School South Carolina have literally broadened their horizons by becoming involved with satellite communications. Live contact with foreign countries give students a fresh perspective and adds dimension to their language and social studies. The use of the rig and the orbital satellite has opened up rare opportunities to our students. Examples include communication with stations in France and Venezuela and contacting a Spanish speaking station, allowed a fellow student from Belton's Spanish class to practice his language skills. For several months local press has followed the progress."

-- Frank Mitchell, Belton Honea Path HS, SC

We will continue to reap the benefits of working with outside agencies, especially educational institutions.

As stated earlier Education is part of whom we are. As seen from our earliest endeavors, AMSAT will continue its educational mission as an inspirational engagement to youth through ARISS and other education outreach endeavors aimed at K-16. It will also engage and cooperate with Colleges and University research facilities to meet our purpose of Keeping Amateur Radio in Space. I have no doubt that such a relationship will advance our ambitions to create quality communication satellites and that such relationship has not only paved our way back to space through Fox-1, but will continue to lead us in the future. I further believe that even our eventual path back to HEO will come from building these relationships.

So, what can you do?

I believe our commitment to participate in developing curricula and addressing STEM related space literacy through the use of Amateur Radio plants the seeds for future engineers and amateur radio space enthusiasts. ARISS continues to inspire and engage and is our premier educational relations tool. However, each of us is an ambassador in our own right. We can do more good in the long run by engaging everyone we can through our demonstrations and sharing our knowledge. I challenge all of us to consider that the mindset and curiosity of the

average 5th grader of our youth exists in every 5th grade student today. I encourage all of us to reach out and be open to teachable moments.

I would like to close by quoting the final paragraph from an article published in the March 1975 QST, "Amateur Radio Boosts Education", by Barbara J. Dirrigl.

"The radio amateur, experienced or inexperienced, using OSCAR opens many options for program participation. One may go directly to a local school to offer services, thus taking the initiative to introduce the school to the OSCAR program, or one may be ready and willing to assist a school in one's area when called upon. An overall need for cooperation and determination are the core in a program as far reaching as this. In a day of increasing depersonalization, direct involvement of the individual is diminishing. What the ARRL/NASA/(AMSAT) Oscar Education Program offers becomes even more valuable as it links the student directly with others in the outside world, giving a sense of individual accomplishment and broadening his otherwise limited scope. Mr. Fred Wise, a teacher at Keystone High School, Knox, Pennsylvania, comments on his success with the OSCAR program.

'From your satellite timetable we were able to make a recording and play it back for class. In an age when the spectacular is commonplace, kids need a little explaining to know how great something like this is. The students seemed amazed to know that we in the classroom could reach out and pick a signal from the sky for our own use. Truly, scientific technology is for those who are willing to reach out and grasp it. OSCAR is within our reach.'

The enthusiastic reception and widespread growth of this program underscore that OSCAR is within reach of many students and teachers who would otherwise only read about satellites and space but never enjoy the intense excitement that in-class live communications hold for them. The educational possibilities are unlimited and the impact upon the student is total and lasting. You, the radio amateur, can share this excitement as ham radio provides yet another public service. You are, in fact, the vital key."

These words are as appropriate today as they were 40 years ago.

References and Acknowledgements

Much of my content was derived by reading through content in old AMSAT Newsletters. I thank Phil Karn, KA9Q, for his excellent database of Historical AMSAT Newsletters. Phil's database can be found at <http://www.ka9q.net/newsletters.html>

Les Rayburn, N1LF collected, scanned, and electronically archived the documents first stored in Phil Karn, KA9Q's archive to also include PDF copies of the AMSAT Journal since the first issue. These are

being made available through AMSAT for a donation. I was privileged to participate in the proofing of the collection and used the opportunity to advance my research.

Barbara Dirrigl's article "Amateur Radio Boosts Education", March 1975 QST was the source for my testimonial information.

Some content was found in an article written by Bill Tynan W3XO for the February 2017 "STATIC", the newsletter of the Hill Country ARC of Kerville, TX titled "My Radio Life".

Bill Pasternak found and reformatted a copy of "OSCAR and the Ham" and made it available to me on extremely short notice.

I'd like to thank Frank Bauer, KA3HDO for challenging me to know my history of AMSAT and ARISS.

And finally I thank my muse, Mark Spencer, WA8SME, who keeps me vented and consistent with my educational philosophies and message.

FunCube Enigma

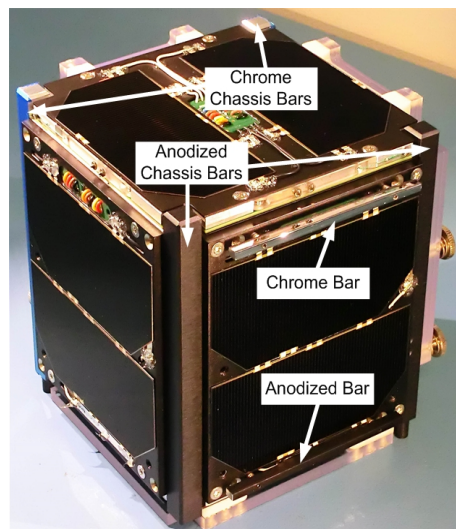
Mark Spencer, WA8SME
wa8sme@comcast.net

Recently I visited my mother who lives in Sun City Arizona. While in the area I had the occasion to drive her car, a white car. It normally wouldn't be a problem except when I went to the local mall shopping. I returned from a trip inside with my purchases only to be faced with a sea of white sedan cars that all looked alike. I had to trip the trunk lid with the remote key fob so that I could identify the right car. So what is the preferred color for a car in a desert climate, dark or light? Obviously intuition points to the white car, it will not absorb as much heat as a dark car. Keep this in mind (even if you don't necessarily agree).

Somehow the opening is related to the FunCube, AO73. AMSAT UK's FunCube has a primary education mission with a secondary Amateur transponder mission. The education mission centers around a materials science experiment which allows students to study heat transfer by radiation. Apparently heat transfer is a specific bullet in the STEM curriculum in the UK. By the way, I have read the UK STEM standards, all 17 pages. In comparison, the US STEM standards are a stimulating 400 plus pages...I like the UK standards better.

The MSE actually consists of two experiments that demonstrate different mechanisms of heat transfer. The Chassis Mounted MSE consists of four aluminum bars, two that are coated with an anodized black surface and two coated with a chrome like shiny surface. Two black chassis bars are mounted at two adjacent edges of the cube, the other two chrome bars are mounted on the other two corners of the cube. The Panel Mounted MSE consists of two identical aluminum strip bars, one black and one chrome covered, that are mounted on one of the faces of the cube, but thermally isolated from the metal structure of the satellite.

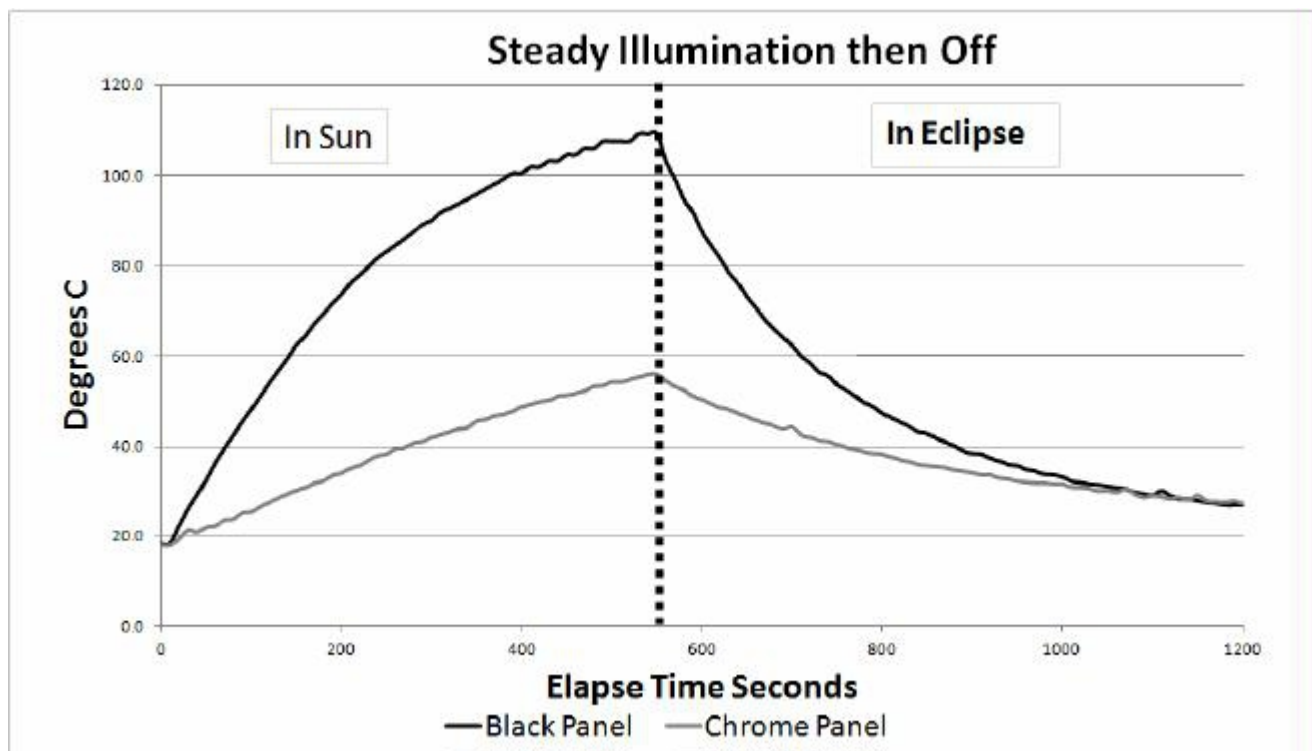
The complimentary bars are identical in material, dimensions, and mass which means they also have identical specific heat and heat capacity, this in turn means that temperature can be used to measure the heat content of the individual bars. What is different between the complimentary bars is that one is coated with an anodized black surface and the other chrome like shinny surface. One thing that has been problematic is that the absorption and emissivity properties of these complimentary bars has not been readily available, and these specific properties would be very helpful in interpreting the data generated by the experiments.



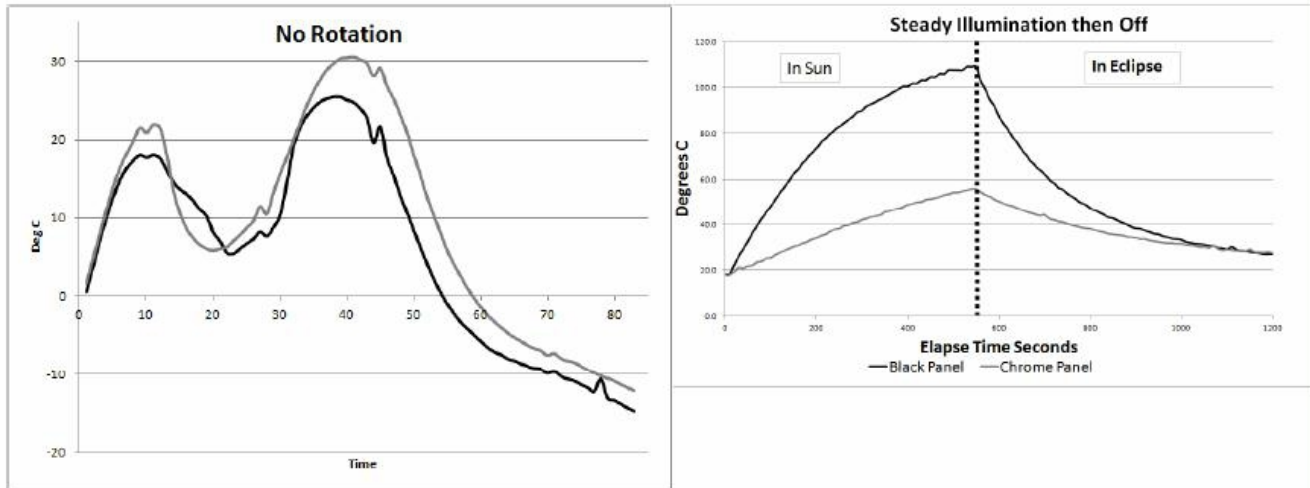
This is a picture of how the MSE bars are mounted on the FunCube.

Notice that the MSE Chassis bars are mounted asymmetrically, if the bars were mounted in opposite corners of the satellite, the bars would be symmetrical. There is no net rotational force applied to the satellite by the Chassis bars because the solar pressures are a net zero. Because the Chassis bars are thermally connected to the satellite's superstructure, there is movement of heat into and out of the Chassis bars by conduction as well as radiation. Alternatively, the MSE Panel bars are insulated or thermally isolated from the panel surface, these bars gain and lose heat only by radiation.

Both experiments have thermistors mounted in the individual bars, and are intended to study heat transfer in a space vacuum environment. The temperature data collected from the MSE bars is reported out in the telemetry, and graphically displayed by the Dashboard software. For educational purposes, the automatic graphing may be convenient, but taking the math out of the data analysis limits the educational value of the raw data.

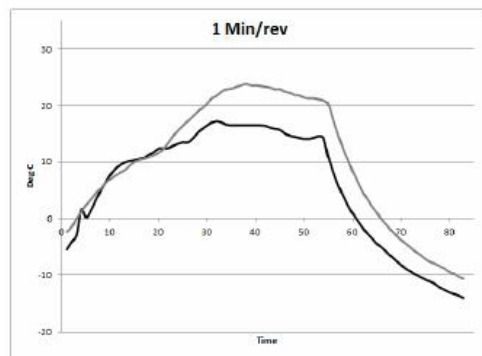


I have developed an in-class MSE simulator that is inexpensive and is actually pretty slick. The simulator uses bar samples of the same aluminum as the real experiment bars. Thermistors are mounted in the bars for measuring the temperatures. I used common household spray paint and aluminum foil to simulate the two coatings of the real bars. A grow-lamp bulb is used to simulate the Sun's radiation. Finally, I simulated the black body environment of space by putting the simulator into a box enclosure spray painted with flat black paint on the inside to absorb heat radiated by the simulator bars and wrapped the outside in aluminum foil to reflect heat from the outside. A large hole in the top of the box is used to allow the light from the grow light bulb to illuminate the bars when turned on and simulating illumination, and a cardboard plate is inserted between the bulb fixture to cover the hole when the lamp bulb is turned off to simulate eclipse (and to help mitigate the residual heat from the bulb). The thermistor data can be collected manually with a volt meter and stop watch, or I have authored a GUI that will plot the data for display and interpretation as shown on the right side of the slide. What is depicted is the lamp is turned on at time zero to simulate coming out of eclipse, the temperatures rise as heat is accumulated in the simulator metal bars, note the black bar temp rises at a greater rate than the chrome bar. At some time interval, the lamp is turned off and the hole covered to simulate entering eclipse. The temperatures decrease as heat is radiated out of the bars, with the black and chrome bar temperatures converging at the ambient temperature.

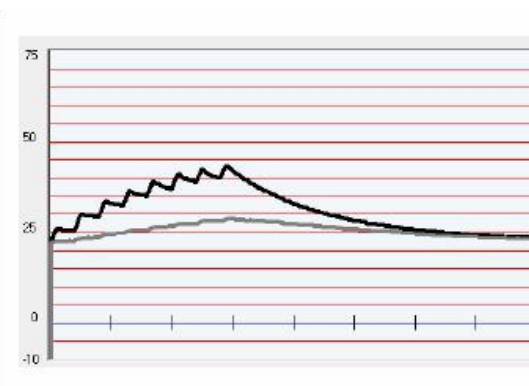
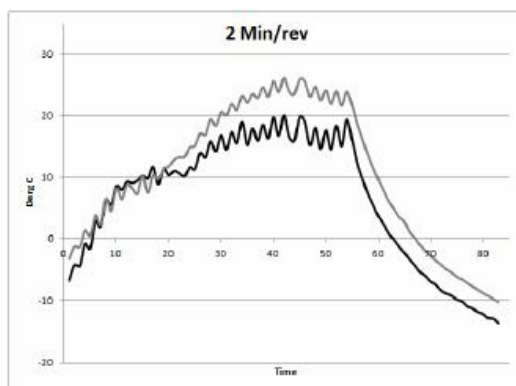
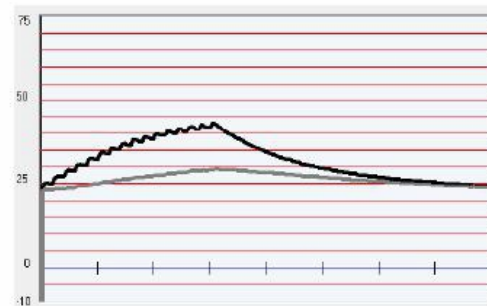


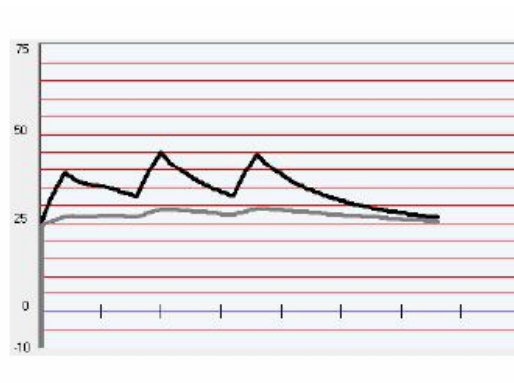
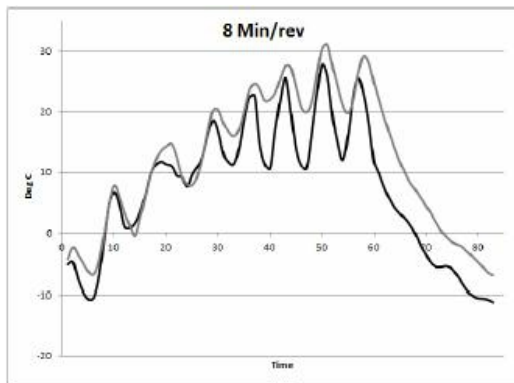
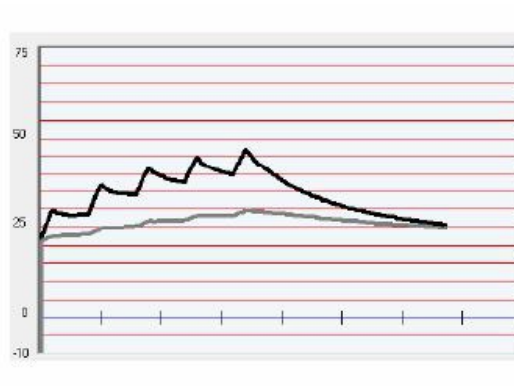
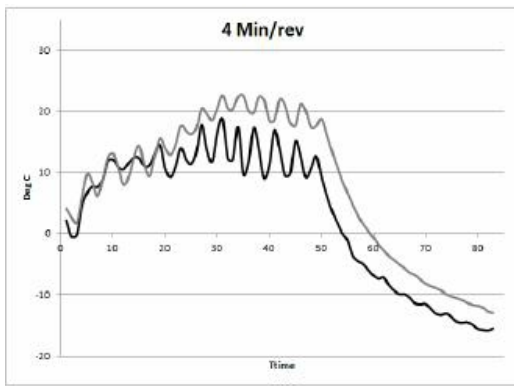
The MSE simulator is remarkably useful in simulating the on-orbit MSE behavior. Here, the plot on the left is actual data when the FunCube had stopped rotating. The apparent hump is probably due to the Z-axis flip maneuver. Clearly the temperatures of the MSE bars rise when illuminated and decrease when in eclipse, as is the case with the simulated data depicted on the right. But notice, the black bar is cooler than the chrome bar in the real data, and the opposite in the simulation. I noticed this discrepancy very early in my work with the FunCube telemetry and it has been driving me nuts ever since.

Real Collection

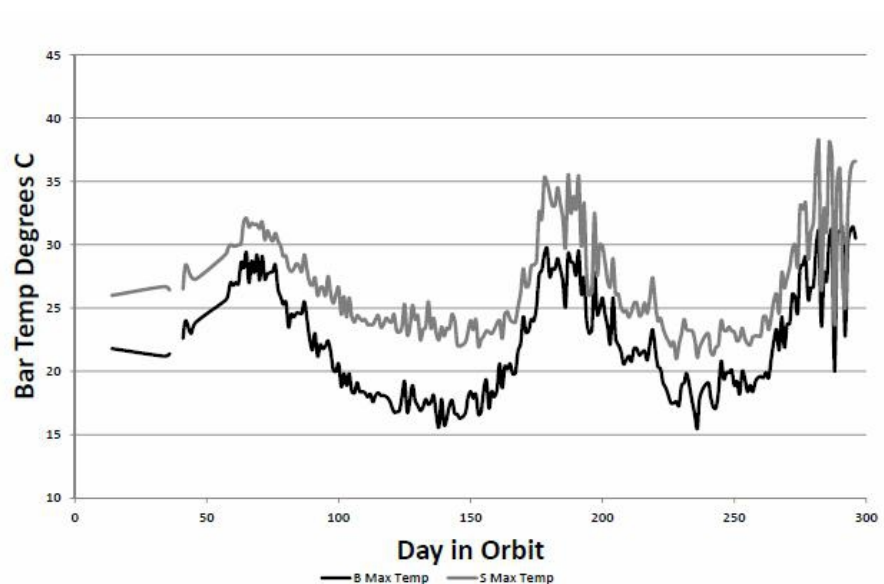


In-class Simulator

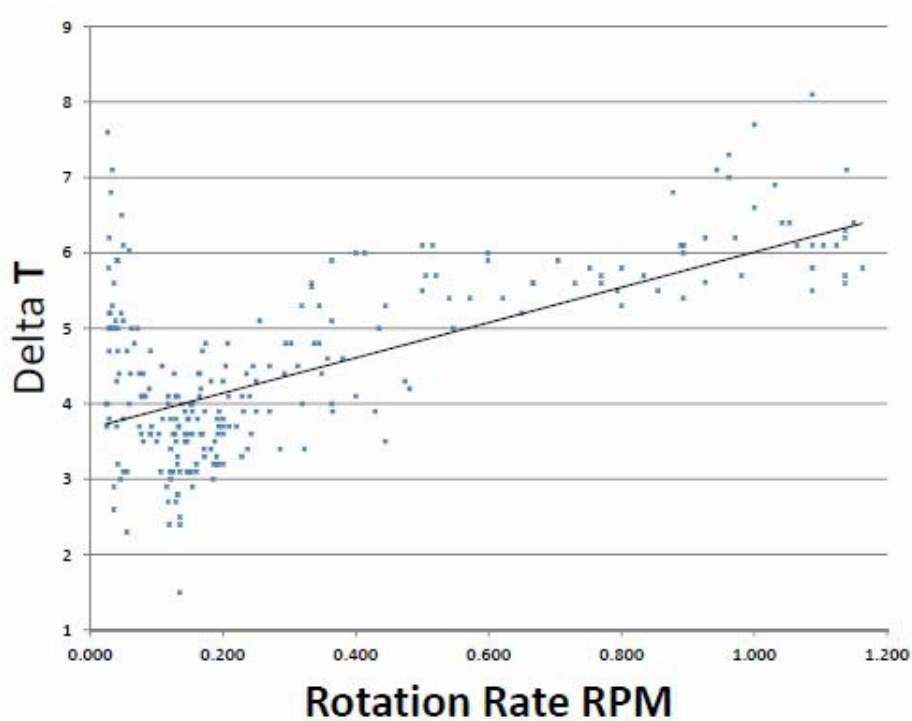




The above slides illustrate how the MSE simulator can be used to demonstrate the behavior of the MSE during the satellites rotation. The grow lamp is simply turned on and off at specific intervals to simulate different rotation rates. Notice that the simulator mirrors the on-orbit behavior. Also note that the intermediate temperature excursions are deeper as the rotation rate slows down. The temperature difference between the black and chrome bars varies as some function of the rotation rate. This can be simulated in the classroom. The object of the simulator is to allow students to set up the operating conditions in the classroom that produce similar results as observed in space, allowing the students to understand the satellite's behavior by testing theories.



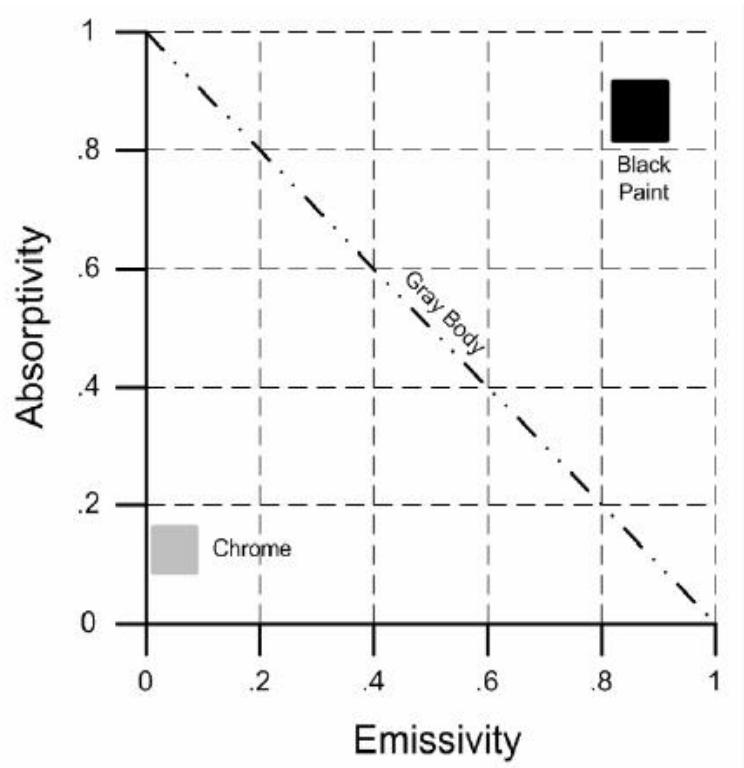
This is the plot of the accumulated MSE temperature and rotation rate data to date. Notice the maximum black and chrome panel bar temperatures and the difference between the maxima vary in step with the rotation rate, this alone provides many learning opportunities for a class to explain this behavior.



This is another view of the temperature differences between the bar temperature maxima as a function of rotation rate, there is a statistically significant correlation.

All this by itself is fascinating stuff, but it still does not address the elephant in the room, why is the chrome bar warmer than the black bar? Common sense tells us the black bar should be warmer than the chrome bar. Heat transfer by radiation is a function of these factors along with absorptivity and emissivity, surface reflectivity, heat sinking and heat sourcing, but many, many more factors in turn makes heat transfer a complex phenomenon. The fact that the answer to the question is not obvious makes for an educational challenge.

I continue to study the relationship between the absorptivity and emissivity of the bars to try and explain the temperature behavior. There are hints somewhere in the data that shows how the inverse relationship between the maximum temperature differences can be explained by cognitively moving the absorptivity and emissivity properties around the continuum of values. The answer is related to some unspecified relationship between absorptivity and reflectivity of the bar coatings. An interesting complexity results where the temperature difference between the black/chrome bar is inversely proportional to the rotation rate (modulation of the heat source/sink)



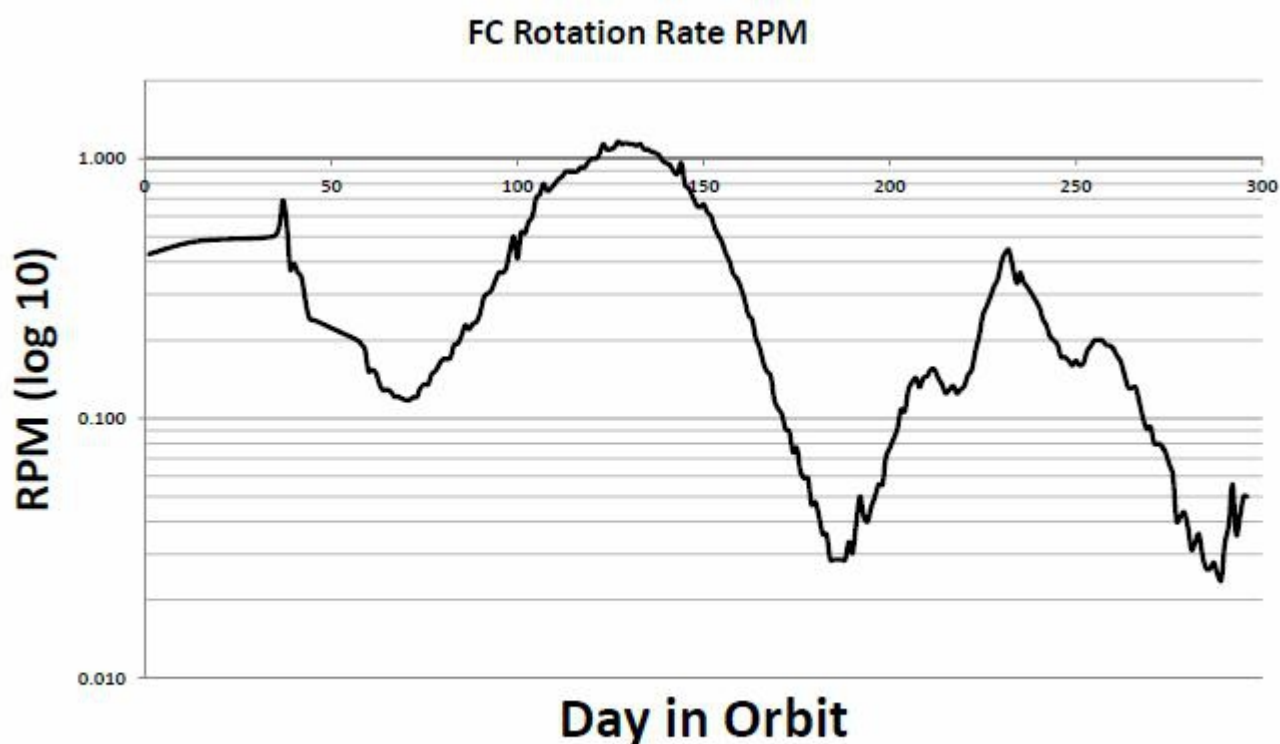
If we assume that the relative positions of the absorptivity and emissivity of the two bars are as depicted here in this continuum of values:

My Best Guess (today)

- Heat retained by Chrome Panel per unit time (.05) is greater than the heat retained by the Black Panel (.036).
- Therefore at any specific time, the Chrome Panel temperature will be greater than the Black Panel temperature.
- This is mathematically due to the ratio of the emissivity/absorptivity of Chrome being .33 versus the emissivity/absorptivity of Black being 1.
 - (Meaning the Black Panel gives up heat at about the same rate as it is absorbed, the Chrome Panel retains more heat than it gives up.)
- This despite the fact that the chrome surface is more reflective than the black anodized surface.

One of the unintended consequences of the MSE is being able to infer the rotation rate of the satellite at very low rotation rates. Traditionally, solar panel voltages are used to determine rotation rate by measuring the time interval between voltage peaks. This is not possible with the FunCube because the panels produce full voltage from the time they are illuminated until the time the bird enters eclipse, there is no cyclical variation that I can detect as the bird rotates around the Z-axis. The FunCube designers installed Sun sensors on one cube face to ping when that face of the satellite faced the Sun. The Fox series of satellites will include MEMS gyros to directly measure rotation rate. For some unspecified reason, the FunCube designers did not install a mechanism to impart rotation to the satellite, nor did they have a target rotation rate. The result is that the FunCube has been rotating chaotically.

The FunCube high resolution Sun sensor data is collected at one second intervals for one minute, and not collected for one minute and the cycle is repeated. This would allow the use of the Sun sensors to measure a rotation rate between 0.25 RPM and 0.03 RPM. This is a mind exercise in the Nyquist frequency.



The majority of the time, the rotation rate is far less than 4 MPR

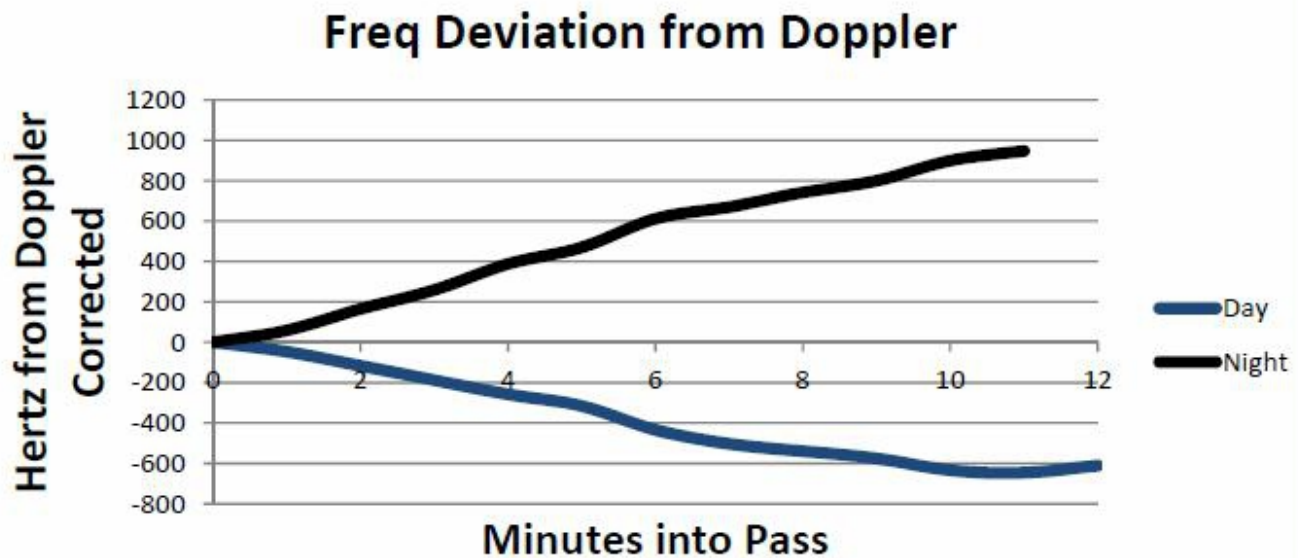
However, the satellite's rotation rate has varied widely since its deployment last November as shown in the plot of the data. Note the Y-axis is logarithmic to help see the dynamic range of the rotation rate. The rotation rate has varied from a high of more than 1 RPM to virtually stopped for all intents and purposes. This range of RPMs required different techniques to infer the rotation rate.

At high rates, the high resolution data can be used as intended, at medium rates, the MSE bar temperatures are useful, at low rates, the solar panel temperatures can be used.

Something happened on December 28th that caused the first abrupt change in the rotation rate. I can only speculate what happened (if anything). While it may appear that the rotation rate is chaotic, there does appear to be order in the randomness emerging from the data. I have looked closely at the data and have not detected

any indication that the rotation direction has reversed as happened with DOVE 17 years ago.

My quest continues to gain insight as to what is happening not only with the MSE behavior but also the rotation behavior of the FunCube. These are just a few of the questions that guide my study. Today, my best guess speculation as to what is going on with the rotation rate behavior has something to do with coupled oscillators (the Z-axis flip maneuver and the rotation of the satellite), and/or the YORP Effect, rotational torque caused by unequal pressures caused by uneven heat radiation.

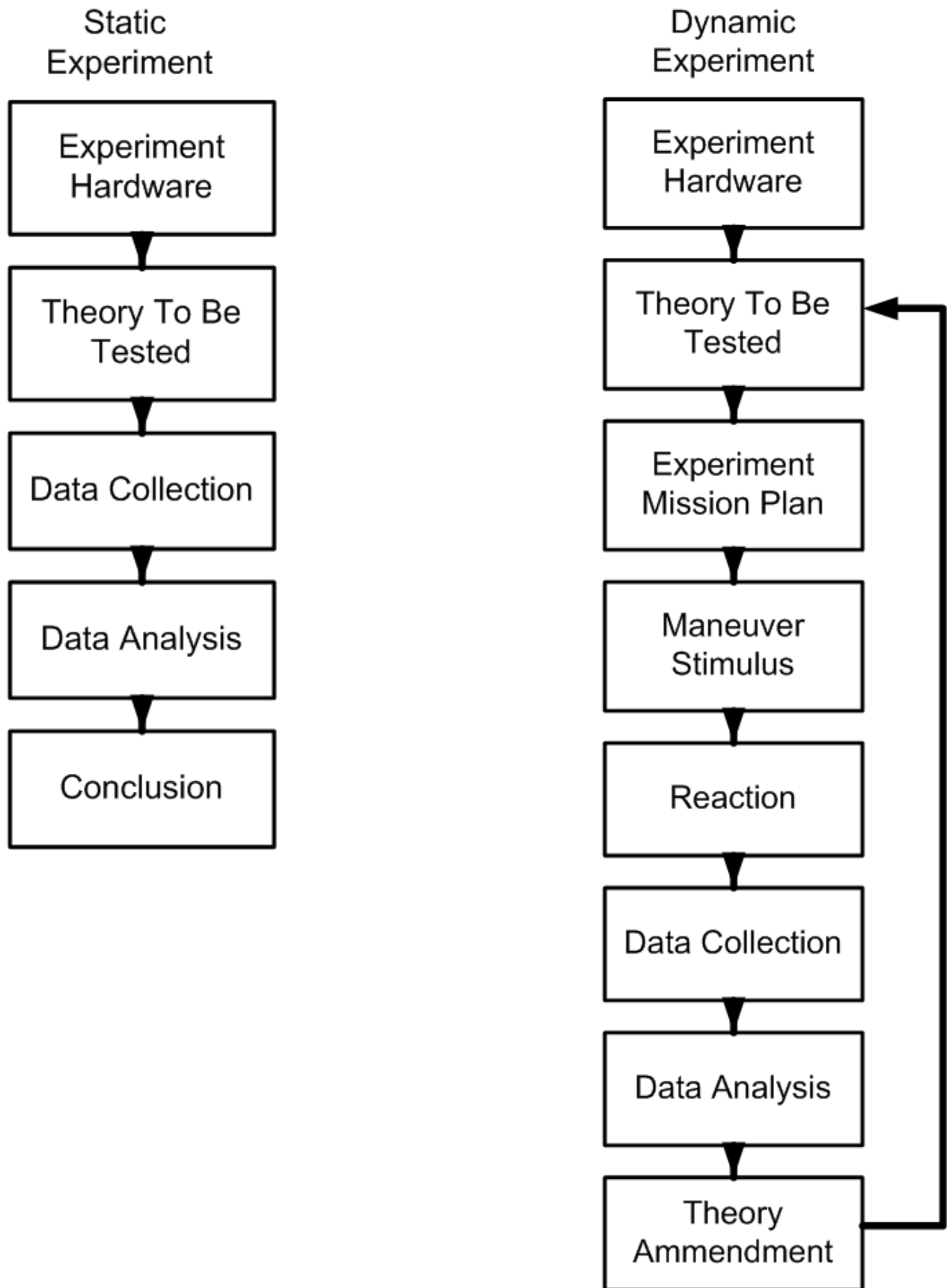


If this were not enough, there is more. Many users had experienced the frequency challenges of using AO-73. Due to the limited power budget, FunCube does not include phase lock loop circuitry to stabilize the oscillators, therefore there is frequency drift due to temperature changes beyond the Doppler shift frequency changes. Analyzing the telemetry data as presented in the Dashboard is one way of studying this property of the satellite transponder. I believe there have been some Amateurs who have used this data to develop software add-ons that compensate their rig's frequency for the temperature drifts, another way that FunCube has stimulated advancements of the hobby.

I too have been exploring other facets of the hobby because of my FunCube experiences. I recently received a small ARRL Foundation grant that I will use to formalize the Leslie's Cube and MSE In-class simulators, and to prototype a circuit to demonstrate the use of reversible magnets as a possible system to manipulate satellite attitudes (this was demonstrated in AO-51), and to explore alternative coatings for future MSE systems. My efforts under this grant will not produce flight ready systems, but will focus on education.

The reversible magnets will be made of the alloy ALNICO. By winding the ALNICO core with a coil and energizing the coil, the magnetic field direction and strength can be altered. During initial testing, it took a pulse of approximately 100 mS at 20 volts to flip the field. The duration of the pulse can be used to vary the magnitude of the field, polarity of the pulse determines the direction of the field.

We Need a Paradigm Shift in Education Missions



Another lesson I have learned from my experience with FunCube, and this lesson is included in the reversible magnet project, is that we need to consider a shift in the way experiments in space are configured. Currently, what I call static experiments are the norm. In a static experiment, hardware is deployed to do a specific experiment, the experiment is conducted, data is collected and reported, and the data is interpreted. Once the experiment is done, it is done, it can be repeated, but the results will likely be the same. The FunCube MSE as it was originally envisioned is an example of a static experiment. A quantum leap in educational value can be obtained if we deploy what I call dynamic experiments. In a dynamic experiment, hardware is deployed with an architecture that allows for flexible employment in multiple experiments capable of many variations. Students develop an experiment plan, the plans are submitted and reviewed by the satellite's operations team, if the experiment will not damage the satellite, the operations team uploads the experiment mission plan, the experiment is executed, data collected and interpreted, adjustments are made or a new experiment is developed and the process is repeated. In all likelihood there is some level of risk to doing dynamic experiments. The satellite community must have some risk tolerance for dynamic experiments to work.

Lessons Learned

- Don't over promise, follow through with what you do promise
- Provide more information, not less
- Develop ground component coincident with on-orbit component
- Develop education component coincident with on-orbit component
- Don't assume the education establishment is ready and willing to embrace your efforts
- Don't assume that teachers (at any and all levels) are ready to teach this stuff, they need training!
- It takes time and resources to execute the education mission...far more than you would think
- Build in flexibility into your satellite – who would have thought that temperature readings would provide such rich learning opportunities?
- Dynamic experiments requires risk, what is your risk tolerance?

As satellite builders and educators, we need to use care not to over promise capabilities and results, proceed with cautious optimism.

We need to provide more information to users not less. “I have a secret that you don't know” just doesn't cut it if you want the users to expend resources using the gift that you are providing them.

A satellite must be treated as a system, the ground segment and education components must be developed coincident with the on-orbit hardware.

We must not assume that the education establishment is going to receive our efforts with enthusiastic open arms. We must not assume that teachers are prepared to teach their students how to use space borne assets. In all likelihood the teachers are just as much learners as their students.

It takes time for teachers to prepare to use new technology in the classroom. It takes on the order of a year and a half from the time teachers receive their initial training on using a satellite in the classroom to when they can even begin to deliver their first lessons in front of the classroom. It also costs money.

We need to build some flexibility in our satellites and be innovative and ready to exploit any unseen opportunities that may arise while the satellite is on orbit. FunCube is an excellent example, there are more learning opportunities because the satellite is not performing exactly as expected. We need to be ready to help educators exploit those opportunities.

Finally, if we are going to embrace an education mission for our satellites, this is going to require extra work collaborating with the education community, in many cases dragging them along. There are risks above and beyond the expected risk of satellite operations.

ARISS 2014: A Program in Transition

Frank H. Bauer, KA3HDO; Gaston Bertels, ON4WF; Debra Johnson, K1DMJ;
E. Mike McCardel, KC8YLD; Lou McFadin, W5DID; Mark Steiner, K3MS;
Dave Taylor, W8AAS; Stefan Wagener, VE4NSA; and Rosalie White, K1STO

Abstract

2014 has been a quite challenging year for the ARISS Program. As the ARISS team prepared for an all-important international meeting in the Netherlands, NASA Education informed us that all funding was dropped for our program and that we needed to start shutting down. In addition, the operations team has experienced somewhat spotty school contact downlink signals from the radio system in the Columbus module. Despite these hurdles, the ARISS-US team was able to restructure its support within NASA to keep ARISS alive and we are working with our space agency and external partners to sustain and grow ARISS in the future. This paper describes the vast variety of ARISS activities and events that were accomplished even as the program struggled to rise up against the unique challenges that threatened its very survival.

Cancellation Challenge and Need for Transition: Keeping ARISS Alive Despite Cancellation Notification

When the international working group called ARISS was newly formed in 1996, ARISS was primarily sponsored by two NASA organizations—Headquarters Education, with support from the Johnson Space Center and the Goddard Space Flight Center, and the ISS Program Office led from the Johnson Space Center. Their in-kind and real-dollar support to ARISS, coupled with the support from the ARRL, AMSAT-NA and our ARISS international partners and space agencies, enabled the ARISS team to

develop a comprehensive program that included hardware development, on-orbit hardware deployment, school group operations, international coordination, lesson plan development and educational outreach.

In the 2009-2012 timeframe, as the ISS was starting to transition from construction to operations, NASA modified the ARISS co-sponsorship with Education and the ISS Program Office. In this timeframe, ARISS custodianship was transferred solely to NASA Education's Teaching from Space (TFS) Education Flight Project at the Johnson Space Center. This change put ARISS (and numerous other education programs) in a very vulnerable position as the NASA Education budget was ten times smaller than the ISS Program Office. NASA Education has also been subjected to large budget cuts—past and present.

In 2013 and in 2014, NASA Education received massive budget cuts. In 2013 ARISS survived the United States government sequester, shutdown and multiple Education budget cuts virtually unscathed because ARISS is a high interest, high priority, high impact, and very low cost educational outreach endeavor for NASA. However, in the spring of 2014, NASA HQ Education lost the bulk of its flight projects funding, requiring nearly all of its flight projects to shut down. In April 2014, ARISS was told that NASA Education was cancelling the program and in August 2014 all support from Teaching from Space, in-kind and real dollar, was terminated. The

result: if no other supporting organization within NASA could be found, then ARISS would no longer be supported by NASA and operations would cease.

Anticipating these dire consequences months prior, the ARISS-US leadership team developed a strategy to form relationships and partnerships with other NASA organizations, outside Education, that might be interested in real dollar and in-kind support of ARISS. We are also formulating partnership strategies with organizations outside of NASA.

Frank Bauer, AMSAT-NA Vice President for Human Spaceflight Programs, had been working with the strategic communication and education office of NASA-Headquarters' Space Communications and Navigation (SCaN) program regarding an ARISS school contact with a science organization in the United Arab Emirates. SCaN has very strong synergies with ARISS. They are responsible for all of NASA's space communication, including ISS communications. They are responsible for NASA's ground stations and TDRS communication relay satellites. They provide spectrum management for the agency. And they have the largest segment of amateur radio operators within any NASA group. Also, they see the importance of ARISS for both its education possibilities as well as its backup communications capability for the ISS.

Frank was able to make the case for direct support of ARISS by SCaN, and real-dollar support has been provided by SCaN to bridge the gap left by NASA Education in Fiscal Year 2014 (which ends September 30, 2014) as well as a major portion of Fiscal Year 2015. This critical funding ensures that our payload operations support (provided by Kenneth Ransom) is sustained,

keeping ARISS operational.

Frank Bauer and E. Mike McCardel, AMSAT-NA V.P. for Education, attended the ISS Research and Development Conference in June 2014 to present a paper on ARISS and to network with teams inside and outside NASA. Prior to this, Frank started discussions with the ISS Program Office and its contractors regarding the future of ARISS. The conference represented an outstanding venue to discuss ARISS' future face-to-face with many of the Program Office leaders, including the Chief Scientist and the leadership of ISS Utilization, where all the payloads are maintained (including ARISS). The ISS Program Office was interested in reestablishing a direct relationship with ARISS and suggested that ARISS was a great educational outreach payload for the ISS National Lab, which is being run for the ISS Program Office by a non-profit organization called CASIS, the Center for the Advancement of Science in Space. (<http://www.iss-casis.org>).

E. Mike and Frank met with several leaders of CASIS during the ISS conference regarding ARISS and future strategies. One of them was the chair of the Education session, who had heard our paper presentation on ARISS the previous day. They all felt that ARISS was a good program fit for CASIS and they ultimately requested that ARISS submit a proposal to officially become an ISS Lab payload under CASIS. That proposal was submitted and, in the meantime, the ISS Program Office began to host ARISS resources, including operations contract support, that were going to be suspended when Teaching from Space shut down in August.

Currently the ARISS-US leadership team is waiting to hear from CASIS, and in the

meantime continues to work with the ISS Program Office and SCan to solidify NASA support of ARISS. Discussions remain to be held with other NASA organizations that have expressed interest in ARISS. And, with CASIS, we are looking at outside organizations for sustained support.

Through all this threat of cancellation and upheaval, the ARISS Program has continued to operate day-to-day and no educational opportunities have been missed. This is a testament to the dedication of the ARISS team, particularly the many volunteers world-wide that make the ARISS Program feasible and so successful.

It is important to note that if the ARISS Program is to remain alive, to be sustained, and to grow, it is critically important that the program develop a team that can garner outside support—in-kind and real dollar support. This will require individuals with skills in business development, fundraising and networking. If you have these skills or are willing to learn, please contact Frank Bauer ka3hdo@verizon.net.

2014 Highlights

ESTEC Meeting

ARISS-International Delegates met at the European Space Agency's ESTEC facility in the Netherlands on April 3-5, 2014—the first face-to-face meeting in 2½ years. Presiding was AMSAT-NA Vice President for Human Spaceflight Programs Frank Bauer, KA3HDO. Participating were Rosalie White, K1STO, as US ARISS Delegate for ARRL (she is also ARISS-International Secretary-Treasurer), Dave Taylor, W8AAS, as US ARISS Delegate for AMSAT-NA, and Stefan Wagener, VE4NSA/VE4SW, as Canadian ARISS Delegate for AMSAT-NA. Also taking part

were US team members Mark Steiner, K3MS; Lou McFadin, W5DID; Kerry Banke, N6IZW; and Tim Bosma, W6MU.

Former ESA astronaut Gerhard Thiele, DG1KIL, welcomed meeting attendees. He heads ESA's Human Spaceflight and Operations Strategic Planning and Outreach office. He said that ESA recognizes the benefit to students of being able to communicate with the ISS crew via Amateur Radio, and said students learn a great deal from ARISS activities.

ARISS Delegates reviewed the program's direction and new objectives, and expressed agreement on wanting to enhance collaboration among all ARISS team members. Talks were presented and discussions were held on current and future technical and hardware topics, including long-term equipment possibilities, education items, operations matters, personnel themes, and more. Some specific examples included Lou McFadin's presentation of the advantages of a mobile VHF/UHF transceiver with higher power capability for the Columbus Module, like the Kenwood D-700 in the Service Module. He spoke about future use of software-defined radios that are remotely controlled from the ground and equipment deployed outside the ISS that is remotely accessed by the crew through portable handhelds or Bluetooth-like devices. In the future, ham gear has to take up very little space in the ISS, and allow for operation across multiple modules. Kerry Banke presented other ideas for enhancing ARISS equipment, and solicited input.

ARISS-Europe Delegate Gaston Bertels, ON4WF, presented ideas for using the Ham Video TV system during school contacts.

Everyone worked together at the meeting as a world team, and momentum surged with

newer team members stepping up to work on new objectives. A number of votes were taken, and the team continues to network on action items suggested during the meeting.

Delegates attended from all five ARISS regions: Canada, Europe, Japan, Russia, and the US. NASA Johnson Space Center Teaching from Space Office representative Trinesha Dixon took part in the meeting via teleconference. The meeting ended with a heart-felt thank you to all team members.

Canada Highlights

The ARISS Canada international delegation went through a full transformation this past year with a change in both ARISS delegates. AMSAT-NA tapped Stefan Wagener, VE4NSA/VE4SW to replace Maurice-André Vignault, VE3VIG/VE2MA who recently decided to step down. And long-time Canada delegate for the Radio Amateurs of Canada (RAC), Daniel Lamoureux, VE2KA, also submitted his resignation this year to focus on some family health situations. As a result, Ian MacFarquhar, VE9IM, was selected as the ARISS delegate for the RAC.



**Stefan Wagener,
VE4NSA**

Key Regional Leaders in the Canadian team include Operations/Mentor team members: Steve McFarlane, VE3TDB, Brian Jackson, VE6JBJ, Wayne Harasimovitch, VE1WPH, Lori McFarlane, School Teacher and Claude Lacasse, Audio/Video specialist, and Canada's member of the Project Selection and Use Committee: Darin Cowan, VE3OIJ

The Canada operations/mentor team was

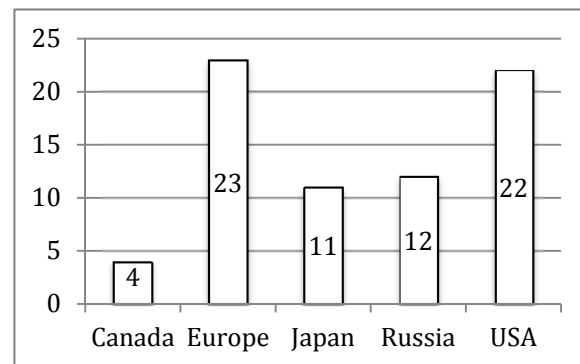
responsible for 18 of the 23 contacts made by Canadian Astronaut Chris Hadfield.

A major initiative that is being mentored by delegate Stefan Wagener is Canada's first ARISS Telebridge station and Ham TV station, VE4ISS, at the Shaftesbury High School, Winnipeg, Manitoba. VE4ISS is now fully operational and fully integrated into the Shaftesbury High School activities, bringing ARISS STEM into the school. All operators (students and teachers) are licensed ham radio operators. ARISS STEM activities include school contact management, radio operation and setup. The students learn the physics of ISS orbits and orbit prediction and they learn about radio waves and radio communication. Prior to their support to ARISS, Shaftesbury teachers Rob Striemer, VE4SHS and Adrian Deakin, VA4AMD received the Canadian Teaching Excellence Award from Prime Minister Stephen Harper for excellence in science and teaching.

Operations Highlights

Educational Contacts

During the past year (September 16, 2013 to September 15, 2014) we conducted 72 successful contacts in 17 countries. This is down from the 95 contacts in 21 countries of the previous year, largely due to program uncertainty and gaps in the program caused



Contacts by Region

by the US government shutdown and periods of no available crew in the US Operational Segment of ISS.

Overall, about 72% of contacts involved a ground station at the students' location. This is slightly above the typical 67%.

Telebridge Changes

As a result of a US proposal at the last ARISS-International Delegates meeting, the ARISS-I Operations Committee has assumed management of the ARISS telebridge network. In this role, they will be responsible for selection and oversight of the telebridge stations. We made this change to enhance international cooperation within ARISS. AMSAT-NA originated the telebridge network for Shuttle contacts during the SAREX program and was responsible for it up to this change.

There are currently nine designated telebridge stations, although currently several of these are unavailable for various reasons, including maintenance. We anticipate adding two stations in the next few months: a new station in Winnipeg, Canada (VE4ISS, at Shaftesbury High

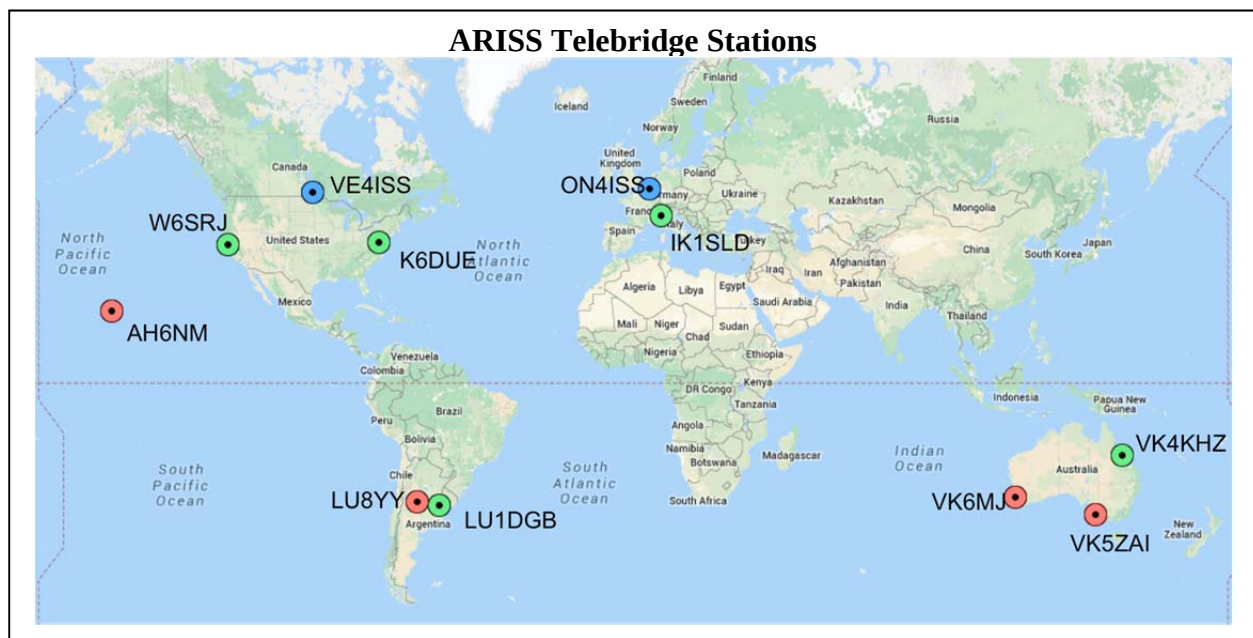
School) and a relocated station in Belgium (ON4ISS).

SSTV Enhancements

The Russian ARISS team has recently been conducting SSTV operations from the Zvezda module. This was made possible by a newly flown cable to connect a laptop to the Kenwood D710 radio and newly updated MMSSTV software. SSTV operation is part of an on-going experiment supported by the Moscow Aviation Institute (MAI) and a new experiment called "About Gagarin from Space". In the past, SSTV transmissions have used Martin 2, Robot 36, and a few other modes. The latest transmissions used the higher definition PB180 mode.

Volunteers

The US operations team is looking for additional help with several jobs, particularly with technical guidance to schools (mentors). We also need someone familiar with Python to modify and help with qualification of some custom orbit prediction software. If you are interested in joining the team, contact Dave Taylor (w8aas@amsat.org).



Educational Outcomes

The US team is completing the schools last selected through the proposal process managed by NASA Education's Teaching From Space (TFS) program and 12 of the schools recruited through partner contacts after the TFS proposal process was shut down. ARISS has about 5 US schools remaining in the queue to be completed. A list of the US schools completed in 2014 is shown in Table 1.

School Feedback

As part of the ARISS activity, we solicit comments and feedback from the schools in a survey we send to each school. Some feedback we received this past year included:

"This was an incredible event. We were able to bring our entire school in on this and it was a pivotal moment for our school year and perhaps the lives of those in attendance. We attempted to bring in some other schools as our guests to the event but that was a challenge given most public schools' inability to be so flexible with their schedules at the last minute."



**Forest Knolls Elementary School
ARISS Radio Station**

"It was amazing. I think it sent chills down the spine of everyone there. I just hope those kids appreciate what a singular and wonderful experience they had. I know I do."

"We had an amazing experience with ARISS! Our technical/radio mentors were excellent and did much to help us prepare for the contact. The engagement of all 900 students present was evident in the silence during the time of contact...a priceless moment for all."



**Students Participating in the ARISS
Contact at the Dorothy Grant
Elementary School**

"It exceeded our expectations! It created a great interest in both amateur radio and in space exploration. We were disappointed that more news media and school officials did not attend, even though invitations and press releases were sent in enough time."

"The experience was very successful and all the students were affected positively, not just those asking questions. The initial minute of the contact was poor quality, with not all questions/answers understood, and the conversation ended more abruptly than I would have liked. However, our students were prepared for all these possibilities."

Educational Topics Explored

From the school feedback, we learned that some of the educational topics explored in preparation for the contact included:

- Living and working on the ISS
- Space History
- The electromagnetic spectrum and radio
- Ham radio etiquette/talking on the radio, basic radio procedures, and oral communication skills
- NASA experiments on the ISS, parts of the ISS, spacesuits, and other NASA/space related topics
- Amateur radio satellites & how they work
- Pre-service teachers completed unit grid and plan on space exploration. An integrated approach to teaching through STEM in Education.
- We had a variety of guest speakers from the ham radio club and NASA Langley. The space topics ranged from rocket science, to living and working in space, to the future of space research.



Radio Communication Education at the Dorothy Grant Elementary School

Additional School Highlights

From the Evansville Day School

The mayor of Evansville declared today as "Evansville Day School Science Day."

<http://www.courierpress.com/news/2014/may/24/eds-students-will-use-ham-radio-to-make-contact>

From the Winfree Bryant Middle School

We had an absolute fantastic experience!!!! We have received emails, texts, and calls from schools all over the United States who watched our contact. Thank you so much for the opportunity to connect the ISS. -- from 8th grade teacher, Tammy Sheppard

<https://www.youtube.com/watch?v=wdNvbWKaHvE>



Winfree Bryant Middle School

MAREA progress

MAREA is an acronym that stands for **Mars Lander/Marine Amateur Radio Robotics Exploration Activity**. It is a hands-on learning activity designed to engage students in learning programming skills for command and control of land or marine robots, and to use Amateur Radio packet communications as the means of communication. Students can access the "network" of Amateur Radio packet stations, including stations on the International Space Station, to relay commands to robots in remote locations, down the hall, in the gymnasium, in a park across town, on a local stream or at a partner school in another state.

Ten teachers were provided a UHF transceiver and the necessary hardware to execute MAREA contacts at the ARRL Teacher's Institute this past summer. They plan to execute packet command of robots

via station to station control. With development of a satellite ground station they will also be able to relay commands through the ISS. This is the beginning of a much larger educational outreach activity that ARISS would like to conduct with MAREA and schools. It will depend on being able to offer teachers more training and resources for satellite ground stations, more reliable access to the ISS packet station and the impetus to get involved with satellite communications activities as more satellite assets become available for teachers to rely upon for classroom use.

School Proposal Solicitation

As NASA's TFS program is no longer supporting ARISS, ARRL and AMSAT-NA are leading the effort to revise the US proposal process and to solicit new ARISS school groups through a request for proposals. Our plans are to open the proposal window for 2015 contacts in October 2014. Two proposal windows are planned per year, a proposal window from October-November and a window from February-March. These will enable January and May selection of schools.

Ham TV

An exciting addition to the amateur radio equipment onboard the ISS was accomplished in 2014: the installation and commissioning of the Digital Amateur Television (DATV) transmitter dubbed "Ham Video" during the late summer. (Ham TV refers to the whole system, including the Ham Video transmitter and contacts using DATV.)

It all began over a decade ago, not with the transmitter, but with one of the other requirements for a radio system: the antenna. Getting permission to use feedlines



Ham Video transmitter for the Ham TV system

that pass through the pressure hull of an ISS module is a very difficult process due to safety concerns for pressurization. ARISS-Europe chairman Gaston Bertels ON4WF took on that challenge in April 2002 when he submitted a request to Dr. Joerg Feustel-Bueschel, the General Manager of the ESA Human Space Flight Directorate. The proposal was to install amateur radio antennas on the nadir of Columbus, the European ISS module then under construction. One of the key parts of the proposal was the feedthroughs that would allow access to the antennas from inside Columbus. On February 19, 2003 a meeting was convened at EADS-Astrium, Bremen where the proposal to install patch antennas on the nadir of Columbus was received favorably.

ESA agreed to let ARISS install patch antennas for UHF, L-band and S-band. Another challenge arose in that ARISS was to support the development and manufacturing. Dr. Pawel Kabacik, professor of the Institute of Telecommunications and Acoustics, Wroclaw University of Technology, Poland, accepted the responsibility to develop and manufacture the antennas. On October 9-10, 2007 L/S-band antennas ARISS 41 and ARISS 43 were installed on the exterior of the Columbus Module in the high bay of

Kennedy Space Center in preparation for launch to the ISS. After a successful launch and installation, ARISS had L/S band antennas on the Columbus Module of the US Operations Segment, accessible from inside the module.

On March 8, 2014 at 13:28 UTC the ARISS International Ham TV system was powered up and operated for the first time by astronaut Mike Hopkins. Transmissions of Digital Television signals on S-Band were sent from the International Space Station to a set of ground stations over Europe and around the world. Commissioning of Ham TV was conducted by a team led by AMSAT-Italy, ARISS-Europe and the European Space Agency, utilizing several amateur radio ground stations set up throughout Italy. Most notably, a large, high-gain dish antenna at the Matera, Italy ground station was employed along with other smaller dish antennas. ARISS has several additional Ham TV ground stations around the world listening and providing reception reports as part of the “blank transmission” mode, a mode where the equipment will be fully operational but with no camera connected.



Mike Hopkins operates Ham TV during commissioning

As many of you know, it is quite a challenge to develop, certify, fly and operate equipment on the ISS. The Ham TV system was presented with additional challenges,

including a wide bandwidth signal that requires very weak signal reception, very high Doppler effects, and S-Band frequencies that are shared with the ubiquitous WiFi signals that are prevalent around the world. The ARISS team has developed several innovative design techniques and mitigation strategies to work around each of these challenges and, as a result, Ham TV experimentation was extremely successful.

The latest information and status on Ham TV is available through the ARISS-Europe site: www.ariss-eu.org and through the ARISS-International website: www.ariss.org.

Hardware Upgrades

One of the challenges being faced by ARISS is the need for a higher-power transmitter in the Columbus Module. The initial transceiver used in the Russian segment shortly after the ISS was first inhabited was the Ericsson radio, transmitting approximately 5 watts through a re-purposed telemetry antenna on the FGB. Later, antennas were mounted on the outside of the Russian Service Module and a Kenwood D-700 was installed to replace the Ericsson. The ARISS community was able to enjoy easy arm-chair copy from the 25 W of output power provided by the Kenwood D-700 in the Service Module.

Currently the only radios approved for use on the Columbus Module are the Ericsson VHF and UHF units, and the Ham Video transmitter. It is a high priority for the ARISS team to install a higher-power radio (such as the Kenwood D710) in the Columbus Module. To accomplish this, ARISS will need to acquire adequate power supplies and the radios, perform safety certification on the equipment, complete the

payload documentation, train the crew, and up-mass the new radio system. This will require additional funding that will not be provided by NASA or other space agencies. We anticipate this will require \$100K-125K.

The success of the Ham TV system, coupled with challenging school downlink signals that have degraded the ARISS school experience, has prompted discussions on increasing the usefulness and capabilities of the resources in the Columbus Module.

Items being considered are:

- A higher-power VHF/UHF/L-band Transceiver (such as Kenwood D-710).
- A suitable power supply to handle all of the current and future components in the Columbus Module. One potential unit would be the Kayser Italia-designed “Portable Power Supply”, or PPS.
- Slide Show and Camera unit based on the Raspberry Pi microprocessor. It would also provide a looping slide show from a file on a standard USB stick, and would allow for continuous Ham TV transmission. This would increase the chances to receive Ham TV on the ground for development and improvement of ground station capabilities.

- Multifunctional Beacon comprised of an S-band CW beacon with telemetry and a transponder function (L-band up and S-band down).

ARISS will be sharing the status of these development efforts ideas as they progress.

Summary and Conclusions

Throughout this challenging year of 2014 the ARISS team was able to keep the program running day-to-day, thanks to the dedication of the ARISS team. 72 schools in 17 countries have had a once in a lifetime opportunity to talk with crewmembers onboard the ISS. A new Ham TV system and improved SSTV capabilities have been deployed onboard the ISS and are ready for utilization. New capabilities are being discussed and developed for future deployment. In the short term, a higher power radio system in the Columbus module is a top priority.

Despite the challenges of this transition year, the future for ARISS is bright. Key to this successful organization and accomplishments are the many volunteers world-wide who dedicate their time and resources to making ARISS the longest-running successful education and outreach payload on the ISS.

1st Quarter				
1/8/2014	direct	Berkeley Middle School	Williamsburg	VA
1/18/2014	direct	Wallingford STEM Academy	Wallingford	CT
2/19/14	telebr	Marymount University/ Ft Belvoir Elementary School	Arlington	VA
2/19/14	telebr	Delaware Township School	Sergeantsville	NJ
2/28/14	direct	Exploration Place	Wichita	KS
3/3/2014	direct	Central Square Middle School	Central Square	NY
3/5/2014	direct	Rock Bridge Elementary School	Columbia	MO
3/14/2014	direct	Warren Consolidated Schools	Warren	MI
3/20/2014	direct	Forest Knolls Elementary School	Silver Spring	MD
2nd Quarter				
4/21/2014	direct	Dixon Elementary School	Holly Ridge	NC
5/1/2014	direct	Hidden Oaks Middle School	Prior Lake	MN
3rd Quarter				
8/2/2014	telebr	Space Jam 8	Rantoul	IL
8/22/2014	Telebr	Zuni Hills Elementary School	Sun City	AZ
8/26/14	Direct	Winfrey Bryant Middle School	Lebanon	TN
8/27/14	Direct	Dorothy Grant Elementary School	Fontana	CA
9/3/2014	Direct	Evansville Day School	Evansville	IN
9/8/2014	Direct	St. Joan of Arc School	Lisle	IL
9/9/2014	Direct	Lanier Middle School and Lanier Cluster Schools	Sugar Hill	GA

US Schools completed in 2014
Table 1

Ham TV History, Status, and Upcoming projects

Gaston Bertels, ON4WF; Lou McFadin, W5DID; Mark Steiner, K3MS

Abstract

In late summer 2014, after years of work on the various components that would come together to support it, an exciting addition to the amateur radio equipment onboard the ISS was completed: the installation and commissioning of the Digital Amateur Television (DATV) transmitter dubbed “Ham Video.”

The Pieces of Ham TV Come Together

It all began over a decade ago, not with the transmitter, but with one of the other requirements for a radio system: the antenna. Getting permission to use feedlines that pass through the pressure hull of an ISS module is a very difficult process due to safety concerns for pressurization. ARISS-Europe chairman Gaston Bertels ON4WF took on that challenge in April 2002 when he submitted a request to Dr. Joerg Feustel-Bueschel, the General Manager of the ESA Human Space Flight Directorate. The proposal was to install amateur radio antennas on the nadir of Columbus, the European ISS module then under construction. One of the key parts of the proposal was the feedthroughs that would allow access to the antennas from inside Columbus. On February 19, 2003 a meeting was convened at EADS-Astrium, Bremen where the proposal to install patch antennas on the nadir of Columbus was received favorably.

ESA’s management decided to install an eightfold feedthrough fixture on the port cone of Columbus. Significant to the ability of ARISS to take advantage of this was their decision to support the cost. An element of the cone was

dismounted and sent to Alenia Spazio in Italy where the fixture was installed.

ESA agreed to let ARISS install patch antennas for UHF, L-band and S-band. Another challenge arose in that ARISS was to support the development and manufacturing. A worldwide funding campaign was launched to cover the cost of the antennas, and 86,000 Euro were collected, nearly enough for L/S-band antennas.

Dr. Pawel Kabacik, professor of the Institute of Telecommunications and Acoustics, Wroclaw University of Technology, Poland, accepted the responsibility to develop and manufacture the antennas. On October 9-10, 2007 L/S-band antennas ARISS 41 and ARISS 43 were installed on the exterior of the Columbus Module in the high bay of Kennedy Space Center in preparation for launch to the ISS. (**Figure 1**) After a successful launch and installation, ARISS had L/S band antennas on the Columbus Module of the US Operations Segment, accessible from inside the module.



Figure 1 - ARISS-41 L/S Band Patch Antenna on Columbus Module exterior (Photo credit ESA/NASA)

All that remained was a system to put inside Columbus.

Ham Video Transmitter

In 2012, at the initiative of AMSAT Italia, a proposal was submitted to ESA's Columbus management by the Italian manufacturer Kayser Italia. The proposal was to build an amateur DATV transmitter for Columbus. ESA accepted the proposal and decided to cover the cost, a major help to ARISS. The transmitter was dubbed "Ham Video." (*Figure 2*)



Figure 2 - Ham Video Transmitter (photo credit ESA)

During 2012-2013, weekly teleconferences comprising ESA, EADS (ESA's support contractor for Columbus payload development and operations), and ARISS representatives were set up to accompany the Ham Video development. Discussions centered on the use of this new capability that was being provided by ESA, including what would be needed on the ground to receive the transmissions.

On August 9, 2013 the Ham Video transmitter was delivered to the ISS by the Japanese cargo spacecraft HTV-4. This demonstrated yet again the unique international cooperation that is the lifeblood of ARISS. Excitement built up for the team that had been helping to integrate and prepare for operations. On Sunday April 13, 2014 at 18.23 UTC the final Ham Video

commissioning step was performed by ISS Commander Koichi Wakata operating OR4ISS while ground stations G4KLB, F6DZP, IK1SLD and at Kayser Italia (Livorno) received the signals and streamed the video over the BATC server (British Amateur Television Club). The DATV signal was received for about 6 minutes.

Commander Wakata congratulated ARISS for this achievement and answered a series of questions, prepared in the manner of a school contact. (*Figure 3*) He also proceeded to perform a microgravity experiment.



Figure 3 - JAXA Astronaut Koichi Wakata, KC5ZTA, is on the air live April 13 during a final commissioning pass of the ARISS ham radio digital TV system onboard the International Space Station. [G4KLB image via BATC server]

The recorded video of this historic transmission is available on the ARISS-Europe website, www.ariss-eu.org.

For the ground segment of the Ham TV system (consisting of the Ham Video transmitter and the rest of the system to get the signals to the end user), the contract signed by ESA with Kayser Italia for the development and manufacture of the DATV transmitter also included delivery of 5 sets of the main constituents of Ham TV ground stations: tripod, 1.2m parabola antenna with feed, down converter, decoder and precision tracking motors. (*Figure 4*) Presently, Ham TV ground stations using this equipment are operational in Western Ireland, central France, North Italy and

South Italy. This selection of ground stations provides coverage of descending ISS passes over Europe and allows 10 minutes of solid Ham Video signals to be streamed over the British Amateur Television Club (BATC) server at <http://www.batc.tv/>. Meanwhile, another chain is under construction for ascending passes with stations in Portugal, France, North Italy, and central Poland. **(Figure 5)**

Jean Pierre Courjaud F6DZP developed software for reception and analysis of Ham Video signals. Measuring the different parameters of a DATV signal is more important for amateur radio experimenters as opposed to just viewing the resulting video stream. His

software, Tutioune, can be found at <http://www.vivadatv.org/>.

A description of a typical Ham TV ground station is available on the ARISS-Europe website. Please see link in left column at www.ariss-eu.org

As the commissioning has been so successful, an ESA-ARISS agreement is presently being prepared to give ARISS permission to use the Ham Video equipment for educational outreach. As part of this agreement the astronaut training equipment developed by Kayser Italia will also be handed over to ARISS.

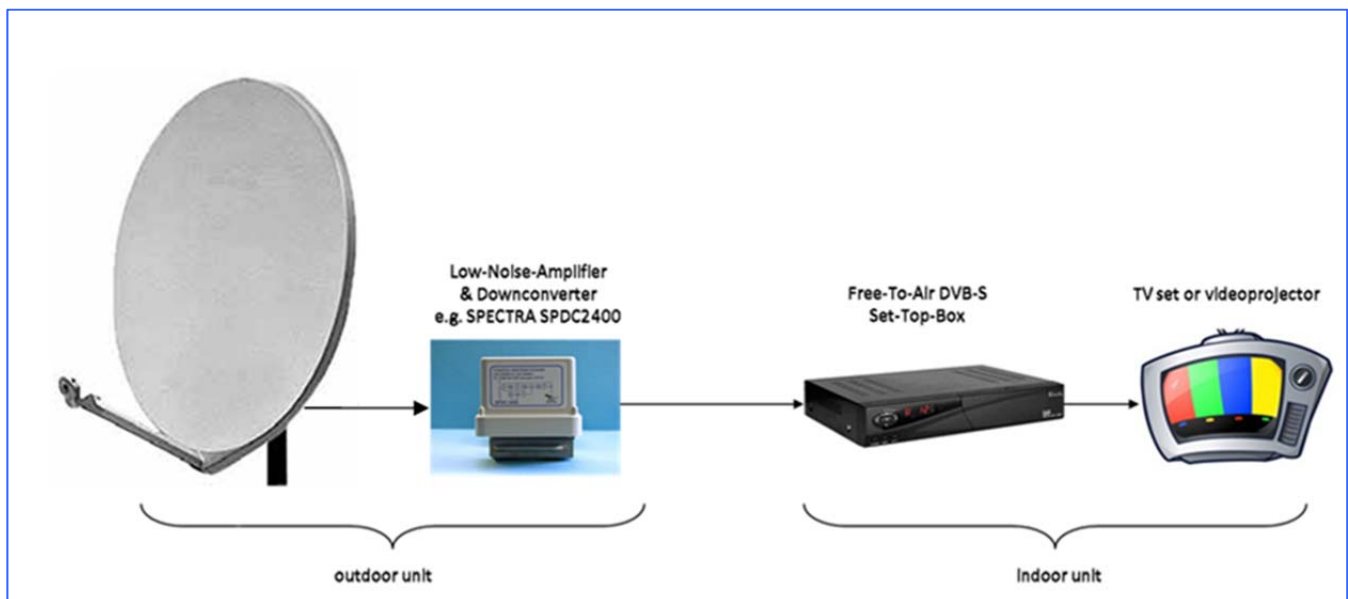


Figure 4 - Representative Ground Station (GS); it mainly consists of a 1 meter diameter offset dish antenna, Left Hand Circular Polarization (LHCP) feed with downconverter/preamplifier (LNB), and a Set-Top Box Receiver. All equipment components are commercially available off the shelf.

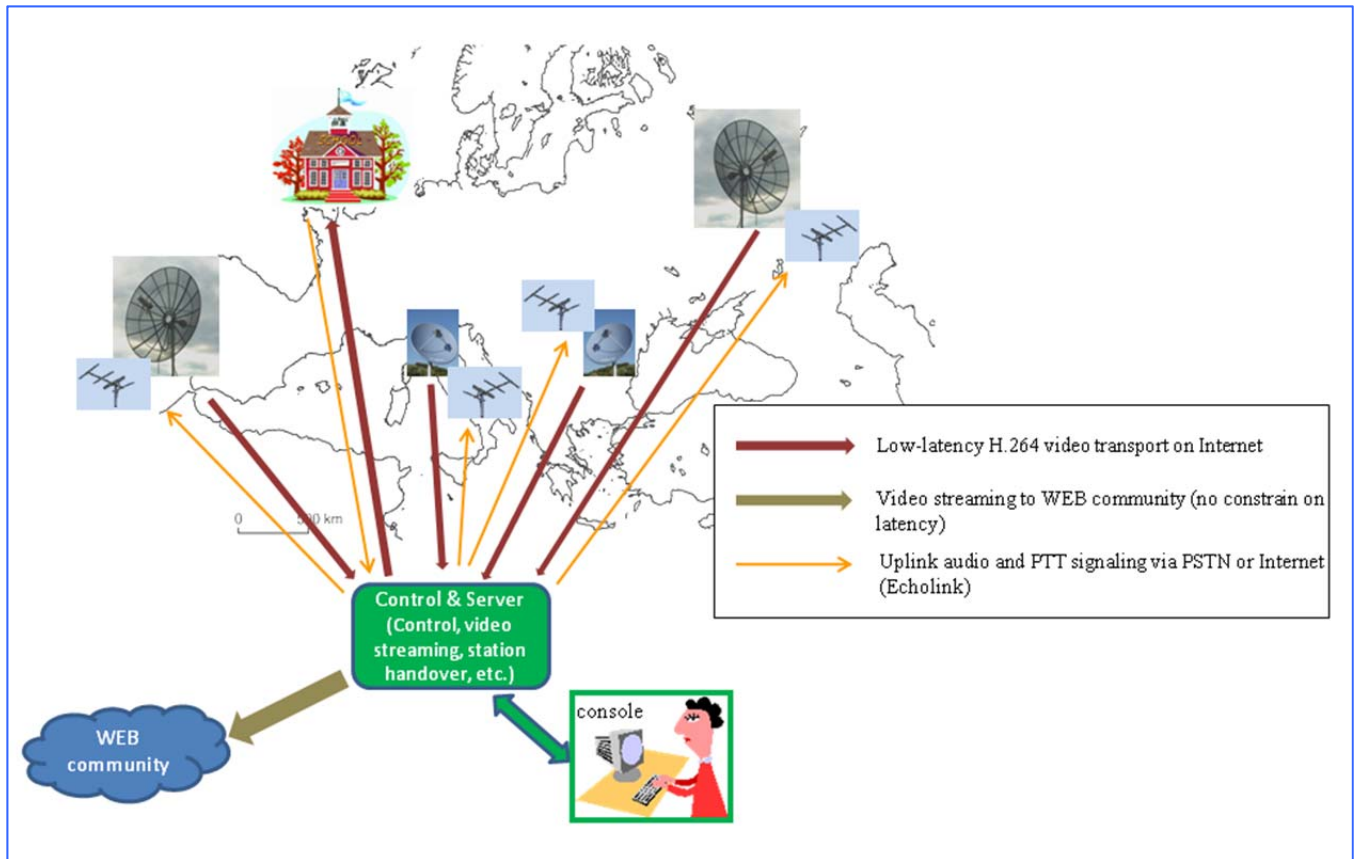


Figure 5 - Ham TV European Chaining Ground Stations

Potential Future Plans

Already the success of the Ham TV system has prompted our ever-eager hams to think about increasing the usefulness and capabilities of the resources in the Columbus Module. Items being considered are:

- A higher-power VHF/UHF/L-band Transceiver (such as Kenwood D-710)
- A suitable power supply to handle all of the current and future components in the Columbus Module. One potential unit would be the Kayser Italia-designed “Portable Power Supply”, or PPS.
- Slide Show and Camera unit based on the Raspberry Pi microprocessor. It would also provide a looping slide show from a file on a standard USB stick, and would allow for continuous Ham TV transmission. This would increase the chances to receive Ham

TV on the ground for development of ground stations.

- Multifunctional Beacon comprised of an S-band CW beacon with telemetry and a transponder function (L-band up and S-band down)

ARISS will be sharing the status of these development efforts as they progress.

Summary & Conclusions

After many long years of planning and flying portions of the system to the Columbus Module, Ham TV is now commissioned for use. Even as the first operational use is just around the corner, many enhancements based on its capability are being considered to enhance its usefulness for education purposes as well as a system on-orbit for the use of those wishing to expand their technical capabilities.

“Extreme DXing on FO-29 with a Portable Station”

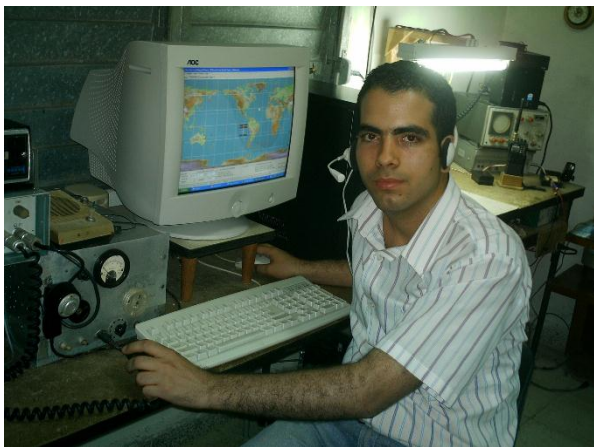
by: Hector L Martinez, CO6CBF/KF5YXV
co6cbf@amsat.org

As a former HF DXer, I became very interested in extreme DX on satellite. The orbits of the linear transponder satellites, such as AO-7 and FO-29, provide the best range, increasing the opportunity for working DX stations. Unfortunately, AO-7 mode B is not legal for Cuban satellite operators. Transmitting on 432 MHz (AO-7 mode B uplink) is forbidden for Cuban hams. With the lack of AO-7 mode B and the issues of mode A downlink on 10m, Cuban operators just have one option to try extreme DX on the birds: FO-29.

FO-29 is a great satellite with a 1300 km apogee, a very stable 1W downlink, and a very generous 100 kHz pass-band. In spite of its eighteen years in orbit, it is still providing an outstanding service to the amateur satellite community [1].

My first extreme DX

Excited for the goal to reach an extreme DX on FO-29 and work Alaska for my WAS award, I emailed Dale, KL7R in BP54. He agreed to try a contact until we were successful! We knew that it could be difficult, but we did not know how difficult! We tried up to 10 times until our success. All SSB attempts failed, but our first attempt in CW was successful! It was my first extreme DX on FO-29 (6720 km). Dale is a very persistent and dedicated operator. He had to climb up a nearby hill in each attempt we did, even at nights and under freezing temperatures.



Hector working Dale from his home station



Dale working Hector from BP54/BP64 grid line

There were two potential reasons which frustrated our first attempts at my end:

- At that time, I was running my all homebrewed satellite station: a homebrewed HF receiver listening to the IF of my homebrewed W6IOJ 70cm down converter for receiving and a homebrewed HF transceiver driving the homebrewed CX9BT 2m transverter for transmitting. Everything was tested with homebrewed test equipments, too. It was the first gear I built for VHF/UHF. I tried to the best I could but I was aware that the 70cm down converter's sensitivity and noise figure were not excellent [2].



Homebrewed satellite gear

-My home station does not have a clear horizon in any direction, except South. There are some tall buildings which shield down 5 degrees every North and West pass. Due East is totally blocked by a very tall building (45m tall).



Obstructed horizon at CO6CBF's satellite home station

My first transatlantic DX

Looking for more FUN and my first transatlantic DX on the birds, I emailed Juan, EA4CYQ in Spain (IM78cx) for a schedule. This contact looked even more difficult! We almost made a

contact in our first attempt. He heard me and came back but because I just barely heard him during a few seconds, I was not able to get his full call sign.

I tried to improve my 70cm reception but I already had done the best I could with my test equipment and homebrewed 70cm converter. I thought about operating portable to overcome the bad location but it was discarded due to the high volume and weight of my SSB satellite gear. We had to wait for a mutual visible pass to try again.

Two months ago after the failed transatlantic contact, I had the highest honor of attending the 30th Annual Space Symposium and I received a lot of donations to improve my satellite station. I became a proud owner of a FT-817ND and ELK dual-band log periodic antenna. Once again, I thank everyone who has made possible these trips and who generously donated stuff to improve my station!

Back in Cuba with my new ham radio gear, I could not wait to get on the air myself. I combined some of my homebrewed gear (30W PA and 70cm LNA) with my new setup. My first goal was the transatlantic contact with Juan, EA4CYQ. We set another schedule and I decided to operate portable from a tall building's rooftop utilizing my new toys. We had a great 7189 km contact! It was the first time I got a solid downlink from FO-29 at my horizon [3]!

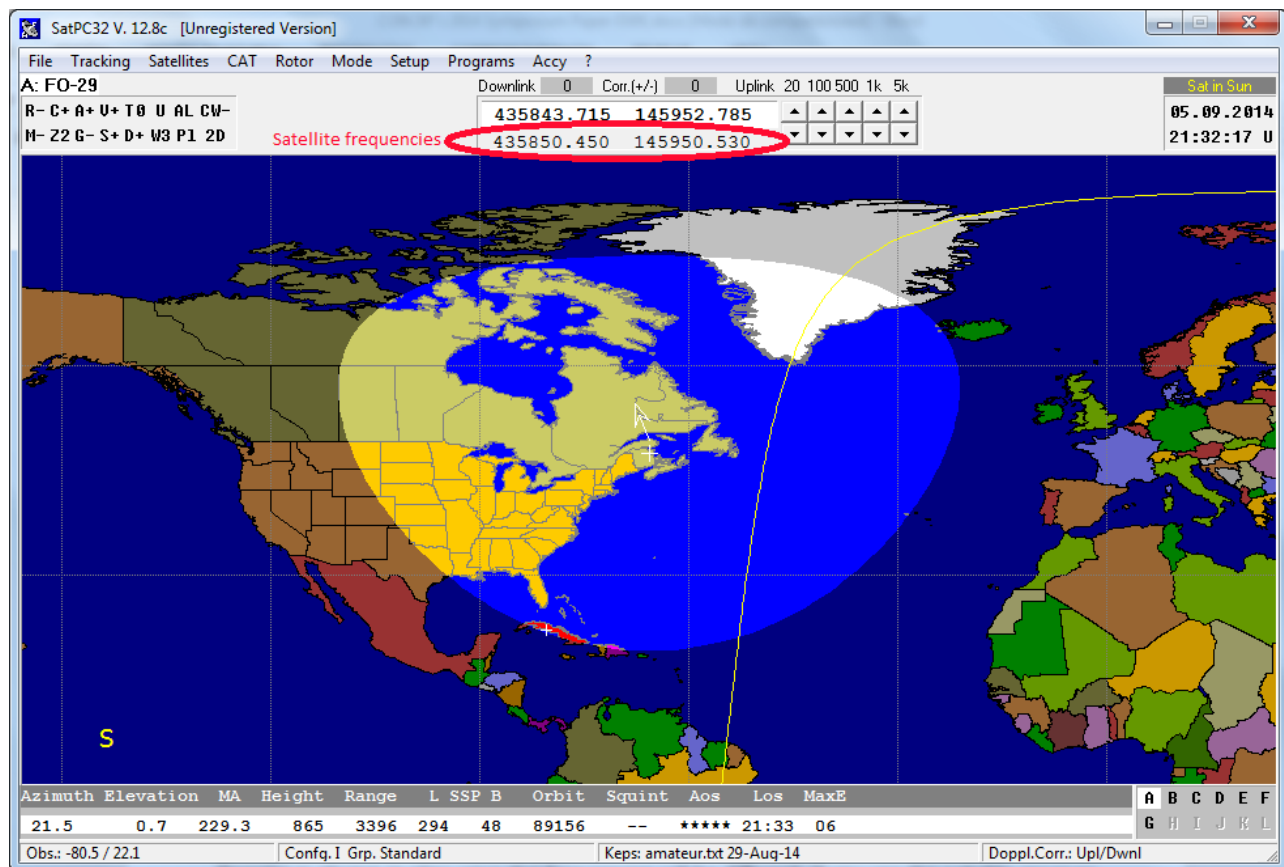
Half – duplex portable setup

Never before hasn't been easier for me! My new FT-817ND and ELK antenna solved all my limitations to work FO-29 from AOS to LOS. Now, I can choose the best location for the pass I want to work. I can go and operate portable from everywhere. FT-817ND and ELK antenna is a very light gear, easy to carry and ready to hear very weak signals.

Yes, it is not a full duplex radio, but half duplex is not terribly hard. In fact, in extreme contacts which have a very limited footprint you may not have time to look for yourself on the downlink. You could waste valuable seconds of a short window trying to do that.

Taking advantage of the great FO-29 frequency stability; my technique is "frequency accuracy". I run calculations based on the great feature implemented on SatPC32 V12.8b.

There is an option of seeing the frequency you are at the satellite receiver at any time during a pass.



SATPC32 tracking FO-29

Doppler is always in play; your dial frequencies will be different. If you use the satellite receiver frequency as common reference point, you will transmit exactly or very close where your desired station is listening, and vice versa. You will be very satisfied when you hear the DX station very close or exactly on the frequency you were expecting!

Another important factor is antenna positioning. Almost always, when FO-29 is over the horizon I got the best signal using vertical polarization. The 100mw beacon is very helpful to track the satellite. I have the beacon's frequency stored in a memory channel while I set the Rx frequency in VFO A and the Tx frequency in VFO B. It makes easier to switch between the beacon's frequency and the QSO frequencies. It is just two touches on the V/M button. Then, you will be able to track the satellite's beacon until the last second before or after both stations get into the footprint.

Horizon visibility is essential. After all, I have taken some benefits from that 45m tall building which blocks the East of my home station; it is a great place to work satellites below the horizon. It is my favorite place to work extreme DX on FO-29!

More FUN

I have continued looking for extreme DX and have been enough lucky to find some adventurous operators who have committed all their efforts to archive an extreme contact with me. A huge thanks to all of them! Each extreme contact on FO-29 is an exciting story! Following my first extreme DX with Dale, KL7R and Juan, EA4CYQ; I have had other long contacts up to 6000 km:

Spain:

David, EA4SG in IN80cp (7330 km)

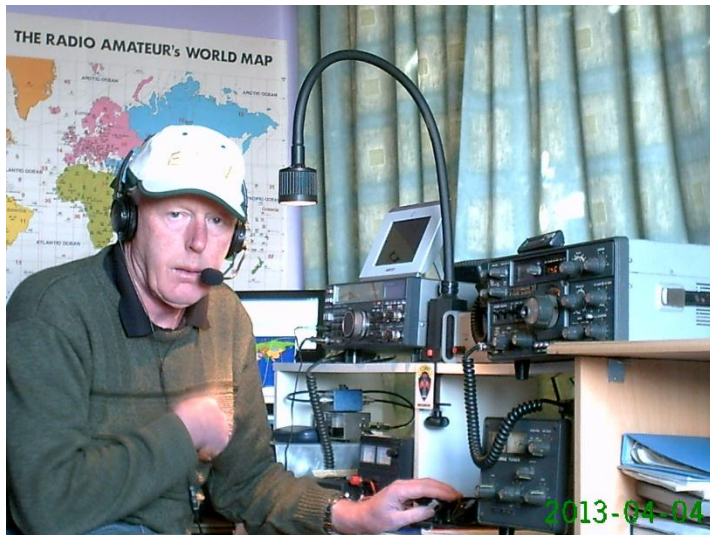
Jose Elias, EB1FVQ in IN52pe (6900 km)

Canary Island:

Hugo, EA8HB in IL18bp (6383 km)

Ireland:

My first contact with Ireland was with Joe, EI5EV in IO62kg. We were successful at our second attempt. It was a 6955 km contact! I was operating from a tall building at my University and was using my usual portable station with a homebrew ARROW antenna.



Joe working Hector from his satellite home station



Hector working Joe from a tall building

My second contact with Ireland was with Michael, EI3GYB in IO53ot (6840 km). He runs vertical antennas for satellite!

Wet grids

Yuri, UT1FG/MM has sailed across the Atlantic, around South America, through the Panama Canal, into the Caribbean and up the Atlantic coast to the St. Lawrence Seaway. I have worked him up to 6000 km away several times. In most cases, I was operating with my portable gear from that tall building.

UK

After six months of work, I achieved a 7286 km contact with Peter, G4DOL in IO80so. We tried several times but Peter never could hear below a degree. I suggested him assemble a portable station to operate from a better spot. He did so, and loaded his car with antennas, radio, and a battery and drove five miles from his home looking for a good spot in the windy and dark coast.

As a great friend and mentor in satellite told me: "A good ham radio operator is one that looks at a problem as a challenge rather than a show stopper"



Hector working Peter from the tall building's rooftop



Peter's antennas at the dark coast

Alaska again

Dale, KL7R was operating from some very rare grids. We made a schedule for each grid he activated. He did a great effort to be on the very early FO-29 passes! It was a very exciting week for me. I had to go to the tall building top, every day! We were successful in all attempts: BP41, BP42, BP51, BP52, BP61, BP62 and BP83 (all over 6500 km) [4].



CO6CBF's portable gear

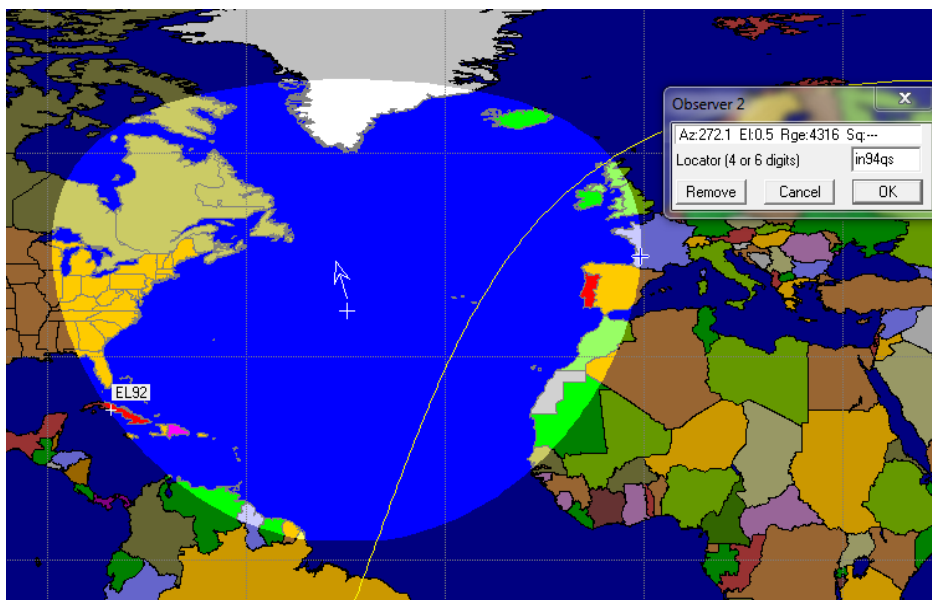


Hector working Dale from the tall building's rooftop

France, my longest DX on the birds

I knew about Michael, F6GLJ and emailed him for a schedule. He agreed but we had to wait almost a month for a mutual visible pass. We just had three mutual visible passes on the next six months.

Our first attempt was on July 18, 2014, but Michael was not able to get a solid copy of my signal. Fortunately, FO-29 offered us another opportunity and we scheduled again. I decided to use the ELK antenna instead of the ARROW which I used in the first attempt. Then, I had my first contact on satellites with France. It is a 7509 km contact, very close to the FO-29 maximum footprint.



Michael, F6GLJ and Hector, CO6CBF into the FO-29 footprint

I was operating from my usual spot on that 45m tall building and I was running my half-duplex portable gear: FT-817ND, a homebrew 50W power amplifier and a homebrew 70cm LNA. Everything was powered by a 12V 7A gel battery.



Hector, CO6CBF working F6GLJ from the tall building's rooftop



F6GLJ's home satellite station

Michael, F6GLJ was running around 80W with an ICOM IC-910 without preamplifier. The antennas were an 11 elements Yagi for 2m and 19 elements Yagi for 70cm at 7m on his roof. Fortunately, He has a good horizon visibility.

I have a good visibility to the South from my full-duplex home station. South American DX has been easier but not less exciting. I have worked some stations up to 6000 km there, too:

Uruguay

Juan Miguel, CX1TH in GF25vi (6892 km)

Argentina

Juan Carlos, LU2DPW in GF05gi (6683 km)

Mario, LU2HAM in FF78up (6190 km)

Brazil

Luciano, PY5LF in GG54gm (6271km)

Chile

Joel, CE2JLB in FF47jg (6130 km)

I hope this information is useful for setting up schedules or filling in any extra information after the QSO.

You could be the next one

I am always looking for new stations, grids, and Countries on the birds. If we have a mutual visible pass, we can make a contact! If you cannot work down to the horizon from your home station, you always can go to a better location and use a portable setup. There is nothing wrong with using a portable setup to work DX. Just do the best with what you have, and you will have FUN!

Notes:

[1] NASDA (National Space Development Agency of Japan). August 1996.

[2] http://mstl.atl.calpoly.edu/~bklofas/Presentations/AMSAT-NA_Symposium2012/Martinez_Cuban_Homebrew.pdf

[3] <http://www.papays.com/sat/general.html>

[4] <https://www.youtube.com/watch?v=R29nW1tepFs>

AMSAT Fox-1 Engineering Documentation Update

**Compiled by Jerry Buxton, N0JY
AMSAT Vice President - Engineering
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AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of the Fox-1 documents were published in the *Proceedings of the AMSAT-NA 30th Space Symposium and AMSAT-NA Annual Meeting* and the *Proceedings of the AMSAT-NA 31st Space Symposium and AMSAT-NA Annual Meeting*, some of these documents have undergone changes as the satellite design has progressed and evolved therefore the updated versions will be reproduced in these 2014 Space Symposium proceedings. In addition, these proceedings also present any new engineering documents that have been produced since the last publication.

Through publication in the three proceedings, the majority of the design documentation has now been introduced to the public domain.

Date: September 29, 2014

Version: Version 1.82

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of *Echo* but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing "Table 6" label
October 17, 2012	1.2	Changed mode descriptions in 3.13.1 Table 6; changed 3.9.2, 3.9.3, 3.9.4, 3.9.5, 3.9.6, 3.9.7 to reflect IHU involvement; changed COMMAND MODE to DATA MODE
April 25, 2013	1.3	3.10.2 Remove PA Temperature, add TX T as RF Transmitter Temperature, OSC T as referring to TX oscillator no longer measured changed to read RX oscillator only
August 20, 2013	1.4	Requirements 3.5.5, 3.6.1, 3.9.6, 3.10.2, 3.11.1, 3.12.4, 3.12.6, 3.13.7.1, 3.13.7.2, 3.13.8, 3.13.9 modified, removed or added to reflect the evolving satellite design
January 10, 2014	1.5	Changes to 3.12.3, 3.12.4, 3.13.2, 3.13.5, 3.13.5.1, 3.13.5.2, 3.13.7, 3.13.7.3, 3.13.7.3.1, 3.13.7.3.2, 3.13.11, 3.13.12 to add Safe Mode
January 20, 2014	1.6	Change 3.13.7.3 to go directly to Safe Mode, remove 3.13.7.3.1 and 3.13.7.3.2
January 23, 2014	1.7	Modified 3.13.2 (figure 1), 3.13.11, added 3.13.11.1
February 10, 2014	1.71	Added "Experiments are powered off" to Table 6 under Safe Mode

DATE	VERSION	SUMMARY
April 17, 2014	1.72	Bring Table 5 commands in line with Command and Control Document, remove PSU reference from 3.12.8 and 3.12.9
August 16, 2014	1.8	Update to actual operating values 3.13.11, 3.13.11.1, 3.12.3, 3.13.1, 3.13.7, 3.13.7.1, 3.13.7.2
September 8, 2014	1.81	Update to actual operating values 3.9.3, 3.9.6, update Table 5, add 3.12.12 and 3.12.13
September 29, 2014	1.82	Update 3.9.3, 3.9.4 to allow for variable hang timer

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from <http://www.itu.int/publ/R-REG-RR-2008/en>

2 General Requirements

2.1 CubeSat Requirements

- 2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.
- 2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.
- 2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.
- 2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.
- 2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

- 2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
- 2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.
- 2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

- 2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

- 2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.
- 2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.
- 2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.
- 2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.
- 2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.6 Experiment

- 3.6.1 The satellite shall provide DC power for experiment payloads.
- 3.6.2 The satellite shall provide a means to activate and deactivate the experiment payloads.
- 3.6.3 The satellite shall provide a means to telemeter data from the experiment payloads.

Note that the experiment payloads will be specified in a separate documents.

3.7 RF Uplink

- 3.7.1 The satellite shall include an FM uplink receiver.
- 3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ± 2.5 kHz (min.)

3.8 RF Downlink

- 3.8.1 The satellite shall include an FM downlink transmitter.
- 3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 In Transponder Mode, the downlink transmitter shall be keyed (*i.e. PTT-on*) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.

3.9.4 In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (*i.e. PTT-on*).

3.9.5 In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.

3.9.7 In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

- 3.10.3 The measured parameters shall be sampled at least every 15 seconds.
- 3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.
- 3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Table 4

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

- 3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

- 3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.
- 3.11.2 The FSK shall use the frequency spectrum below the audible range.
- 3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.
- 3.11.4 The telemetry transmission shall include telemetry frames.
- 3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

- 3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.
- 3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.
- 3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	Operation
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode

3.12.4 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.5 An INHIBIT TX command shall disable the RF transmitter.

3.12.6 An ENABLE TX command shall enable the RF transmitter.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A DATA MODE command shall cause the satellite to enter the Data Mode.

3.12.12 An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.

3.12.13 A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	Description
Startup Mode	Wait 50 minutes and deploy antennas
Safe Mode	Wait 120 seconds then begin 10 second beacon sequence Experiments are powered off

AMSAT Fox-1
System Requirements



Transponder Mode	FM transponder; PTT and low speed telemetry via IHU
Data Mode	FM transmitter; PTT and high speed telemetry via IHU

3.13.2 The satellite shall transition between modes as shown in Figure 1.

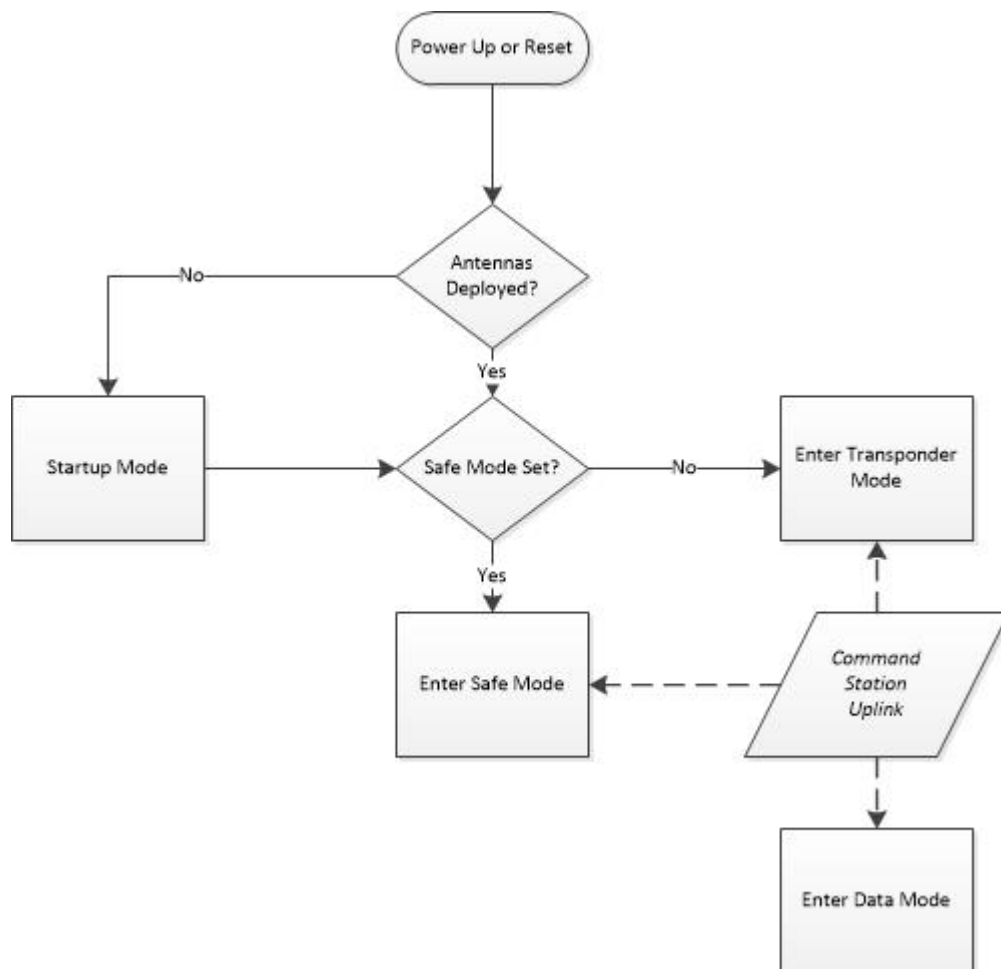


Figure 1. On-Orbit Operating Modes

- 3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.
- 3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.
- 3.13.5 If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.
 - 3.13.5.1 If the last state was Safe Mode the satellite shall enter Safe Mode.
 - 3.13.5.2 If the last state was not Safe Mode the satellite shall enter Transponder Mode.
- 3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.
- 3.13.7 In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.
 - 3.13.7.1 During the 50 minute wait the IHU shall flash a red LED.
 - 3.13.7.2 During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.
 - 3.13.7.3 After the antennas have been deployed the satellite shall enter Safe Mode.
- 3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.
- 3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (*i.e. signals that appear on the uplink shall not be repeated on the downlink.*)
- 3.13.10 If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.
- 3.13.11 In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.
 - 3.13.11.1 The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.
- 3.13.12 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specifications

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: September 29, 2014

Version: 3.92

AMSAT Fox-1

Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT Fox-1 satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice
October 17, 2012	3.15	Import changes to requirements from System Requirements
February 17, 2013	3.2	Incorporate system bus signal nomenclature and pin assignment changes
February 28, 2013	3.3	MEC connector changed orientation (flipped) on +X -X +Y -Y panels.

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Avionics System Design Specification



DATE	VERSION	SUMMARY
March 28, 2013	3.4	Add second –Z PPOD deploy switch (pin 54), PPOD deploy switches now on TX system card
March 31, 2013	3.41	Updates to the TX, RX, IHU, and BUS pin diagrams.
March 31, 2013	3.42	Adjusted RESERVED pin colors only
April 21, 2013	3.43	Addition of RX Frequency Control, TX Frequency Control, and Sensor Power signals Pin reassignments: Moved pins 52 and 54 to pins 33 and 35 respectively Moved pins 40 and 42 to pins 29 and 42 respectively Added the above new signals to pins 42, 40, and 38 respectively
April 25, 2013	3.5	Update per System Requirements 3.10.2 changes. Updated bus connection pin assignments, bus interconnect diagram, and system bus signal characteristics account removal of TX OSC Temp and TX PA Temp and addition of TX Temperature
June 26, 2013	3.6	Add requirements for PSU and BATT1 CPU reset from RX Command Data, updated IHU block diagram
July 24, 2013	3.7	Add ALERT signal, SENSOR POWER signal, remove RBF2, rename RBF1 to Solar Safe N, remove RX Command Data connection from BATT1, flip MEC connector orientation on +X, -X, +Y, -Y panels, update ME-113 mechanical drawings
August 26, 2013	3.8	Rename RX OSC TEMP to RX Temperature, add Initial Surge Current Limits for certain systems, move Command Decoder to IHU system (bus pin changes), update some bus nomenclature, update System Requirements for each system per changes to the System Requirements
August 27, 2013	3.81	Correct source and destination for RX Command Strobe in Table 1
September 17, 2013	3.82	Add (move) RSSI to Pin 10, rename Pin 32 as RX CD, add Solar Power A and Solar Power B to pins 55 and 56, update TX Block Diagram, remove RX Command Data connection from PSU, update hyperlinks.
October 8, 2013	3.83	Remove IHU AUDIO OUT 2, RX AUDIO 2 signals, rename IHU AUDIO OUT 1 to IHU AUDIO OUT, RX AUDIO 1 to RX AUDIO.
November 11, 2013	3.84	Updated IHU Block Diagram
January 23, 2014	3.85	Add Sensor Power connection to PSU
January 23, 2014	3.86	Several text (requirements) changes to match recent System Requirements change for Safe Mode.
April 27, 2014	3.87	Add PCB plating requirements for TX, RX, IHU, PSU, BATT, EXP systems
May 29, 2014	3.88	Correct 6.7 to read PSU System
August 16, 2014	3.9	Updates to 5.1, 6.1 to match updated system requirements
August 20, 2014	3.91	Correct 5.1 to show 120 seconds for Safe Mode beacon
September 29, 2014	3.92	Update PSU block diagram, add receiver block diagram, update commands in 5.1, update instances of system requirements 3.9.3, 3.9.4, 3.9.6



1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT *Fox-1* System Requirements Specification.

1.4. References

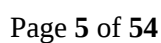
1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus (Signal Connections Diagram)
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-120_Z_TOPBOTT_SOLAR_PANEL.pdf
7. AMSAT FOX-ME-127_Y_SIDE_SOLAR_PANEL.pdf



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FOX-1 Signal
Connections Diagram



AMSAT Fox-1

Avionics System Design Specification



Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
5	SPI1 MISO	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
6	Experiment 4 Thermistor	Analog	N/A	EXP 4	N/A	IHU	Temperature from Experiment 4 position
7	SPI1 MOSI	Digital	Note ¹	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	Async, Mark High
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	Async, Mark High
12	IHU Audio Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	Not Used						
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 0	Digital		IHU			(Least Significant Bit) Not Used on Fox-1A
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 1	Digital		IHU			Not Used on Fox-1A
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 2	Digital		IHU			HIGH = IHU off
21	Not Used						
22	RX Command Data 3	Digital		IHU		TX	(Most Significant Bit) HIGH = Inhibit Transmit
23	I ² C1 SCL	Digital	Note ¹	IHU			I ² C Standard, IHU Master
24	RX Command Strobe	Digital		IHU			HIGH = Command Data change
25	I ² C1 SDA	Digital	Note ¹	IHU			I ² C Standard, IHU Master HIGH = IHU Controls RF LOW = Standalone Analog Transponder
26	IHU RF Control	Digital		IHU		TX	
27	Not Used						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	Solar Safe N	Switch	N/A	BATT	N/A	PSU	N.O. for operation
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
31	Alert Signal	Digital		IHU		BATT	
32	RX CD	Digital		RX		TX IHU	HIGH = valid receive signal
33	-Z Deploy Switch 1	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
34	RX Audio	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth
35	-Z Deploy Switch 2	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
36	Not Used						
37	I ² C2 SCL	Digital	Note ¹	IHU		PSU/BATT	I ² C Standard, IHU Master
38	Sensor Power	Analog	+3 VDC	IHU		TX RX BATT EXP4	Power for analog telemetry sensors
39	I ² C2 SDA	Digital	Note ¹	IHU		PSU/BATT	I ² C Standard, IHU Master
40	TX Frequency Control	Digital		IHU		TX	Not Used on Fox-1A
41	+Z Thermistor	Analog	N/A	EXP 4	N/A	PSU	
42	RX Frequency Control	Digital		IHU		RX	Not Used on Fox-1A
43	-Z Thermistor	Analog	N/A	TX	N/A	PSU	
44	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
45	+Z CIC	Power	N/A	EXP 4	N/A	PSU	
46	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
47	-Z CIC	Power	N/A	TX	N/A	PSU	
48	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
49	Umbilical USBP	Digital		BATT		IHU	USB Standard
50	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
51	Umbilical USBM	Digital		BATT		IHU	USB Standard
52	Not Used						
53	Umbilical Power Active	Digital		BATT		IHU	HIGH = Running on Umbilical Port Power
54	Not Used						
55	Solar Power A	Power	Vbatt	PSU		BATT	
56	Solar Power B	Power	Vbatt	PSU		BATT	
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	

Version 2.96

Note¹ All SPI and I²C signals are 3.0 V levels All Digital signals are 3.0 V CMOS logic levels high impedance load unless otherwise noted

AMSAT Fox-1
Avionics System Design Specification

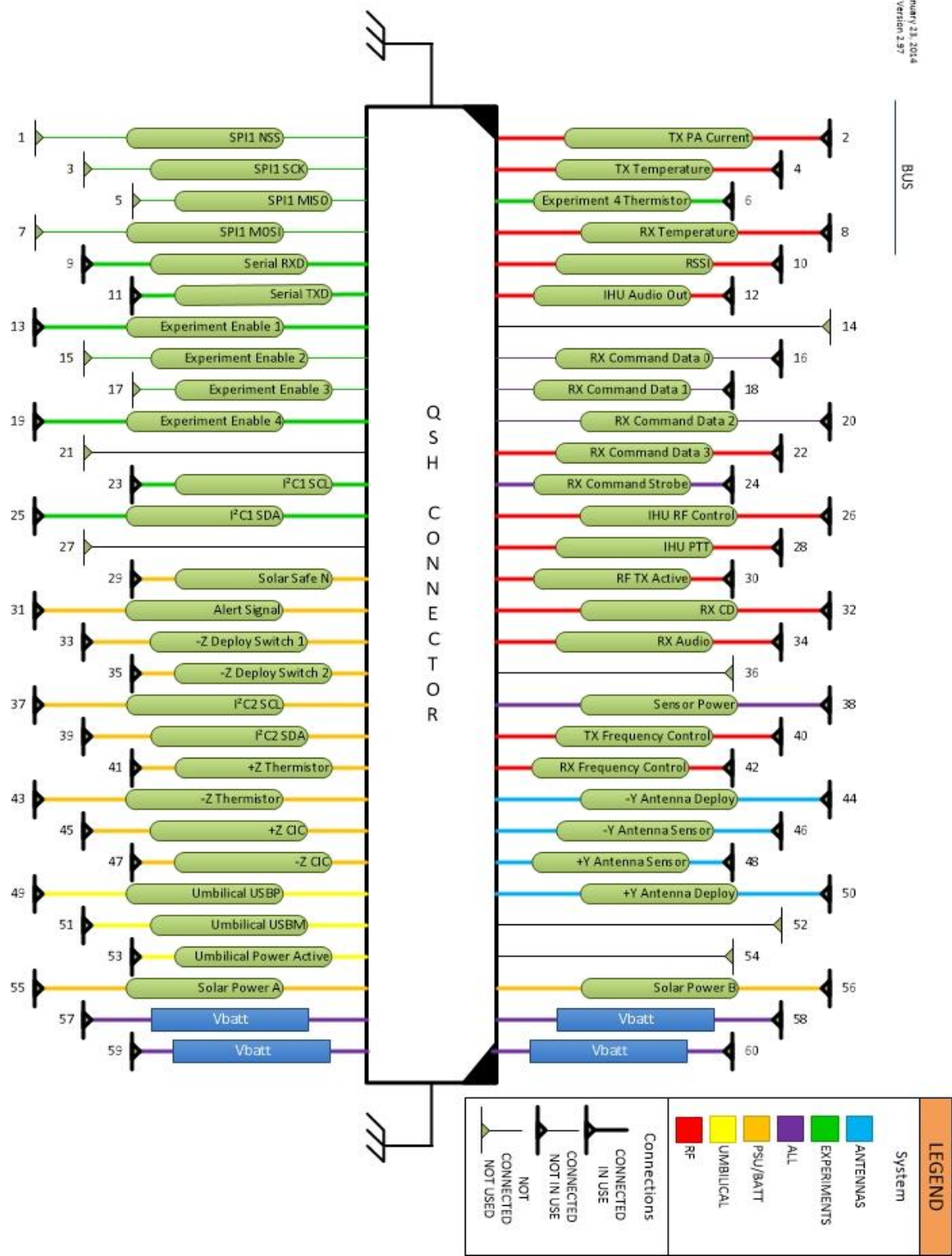


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.		
2.4.1	All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.		
2.4.3	All satellite downlinks shall be in the 2 meter band within the amateur satellite service.		
2.4.4	All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.		
2.4.5	All satellite frequencies shall be coordinated with the IARU.		
3.8.1	The satellite shall include an FM downlink transmitter.		
3.8.2	The transmitter shall have specifications as shown in Table 2.		
		Power Output	400 mW (min.)
		FM Deviation	5 kHz
		Audio Bandwidth	3 kHz
3.8.3	The transmitter shall provide a means to prevent over modulation.		
3.9.1	The satellite shall provide an FM transponder via the RF uplink and RF downlink.		
3.9.3	In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.		
3.9.5	In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.		
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.		
3.10.1	The satellite shall collect telemetry data.		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3.		
		Parameter Name	Description
		CELL V	Voltages of battery cells
		PANEL V	Voltages of solar panels
		TOTAL I	Total DC current out of power system
		PA I	DC current into RF power amp
		BATTERY T	Temperature of battery
		PANEL T	Temperatures of solar panels
		TX T	Temperature of RF transmitter card

		RX T	Temperature of RF receiver card	
3.10.3	The measured parameters shall be sampled at least every 15 seconds.			
3.11.1	The satellite shall send slow speed telemetry using FSK on the RF downlink.			
3.11.2	The FSK shall use the frequency spectrum below the audible range.			
3.11.3	The telemetry shall be transmitted simultaneously with any transponder communications.			
3.12.1	The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.			
3.12.2	The commands received via the RF uplink shall not be repeated on the RF downlink.			
3.12.3	The following commands shall be provided, as shown in Table 5.			
		Command	Operation	
		SAFE MODE	Enter Safe Mode	
		INHIBIT	Inhibit RF transmission	
		IHU OFF	Power off IHU & PSU	
		IHU ON	Power on IHU & PSU	
		CLEAR	Clear stored telemetry	
		TRANSPONDER MODE	Enter Transponder Mode	
		DATA MODE	Enter Data Mode	
3.12.5	An INHIBIT command shall cause the satellite to cease RF transmissions.			
3.13.8	In Transponder Mode, the transponder and the slow speed telemetry shall be active.			
3.13.9	In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)			



3.2 Initial Surge Current Limits

3.2.1 The RF Transmitter design shall limit initial inrush current to 2.5 Amperes.

3.3 Volume Requirements Applicable to RF Transmitter System

3.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the -Z surface of the PC board.

3.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.4 Interface Control Documents Applicable to RF Transmitter System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

3.5 PCB Plating Requirements Applicable to RF Transmitter System

3.5.1 ENIG then selective flash gold four mounting pads.

3.6 RF Transmitter System PCB Bus Connections

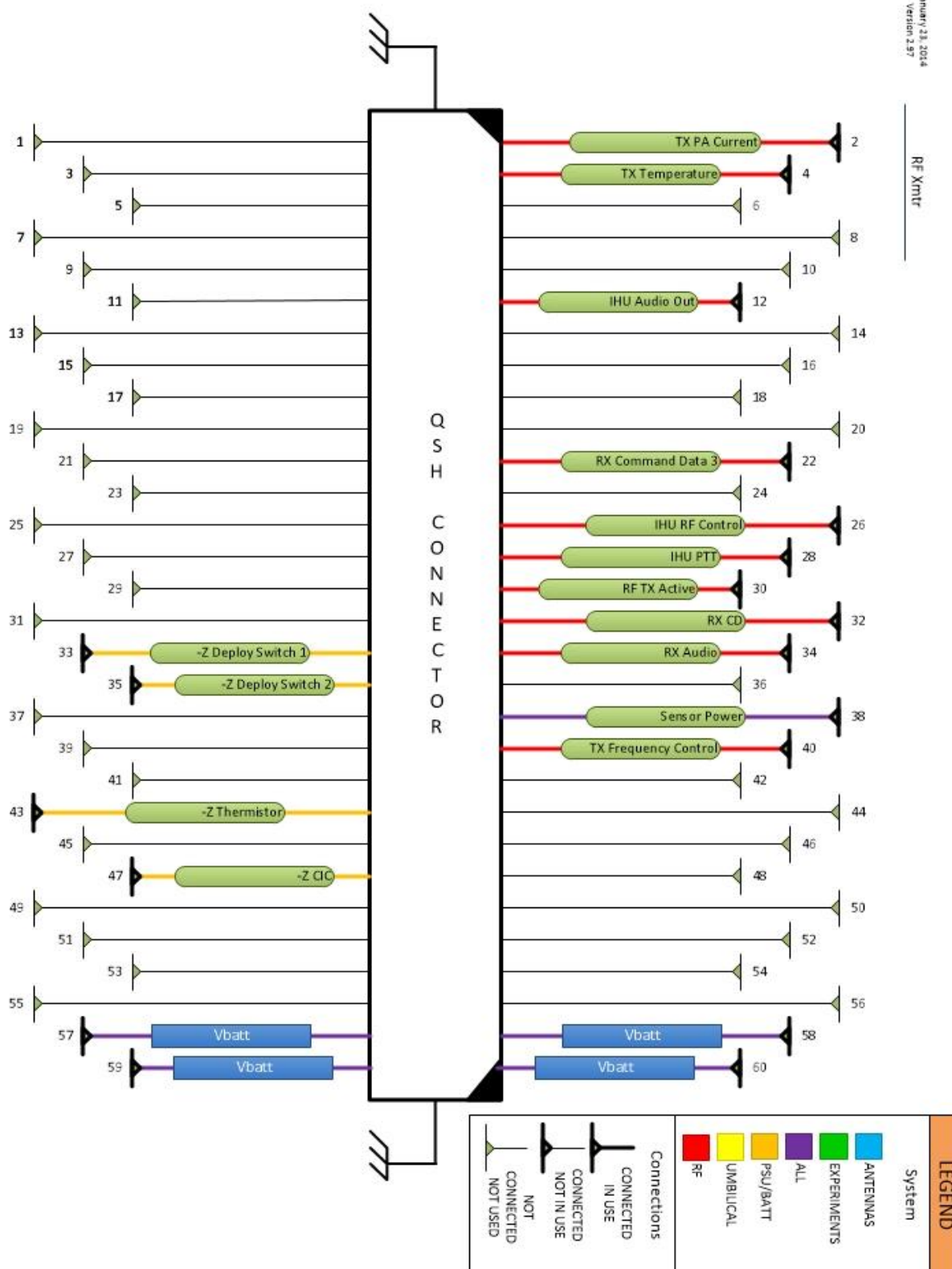


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.7 RF Transmitter System PCB External Connections

3.7.1 2 meter band RF output, coaxial cable to Transmit Antenna

3.7.2 Spacecraft deployment switches cable(s) TBR

3.7.3 Three connections via Samtec FSI-105-06-L-S-AD connector

3.7.3.1 1 contact -Z Solar Panel Thermistor

3.7.3.2 1 contact -Z Solar Panel CIC +

3.7.3.3 1 contact common or - for above four connections

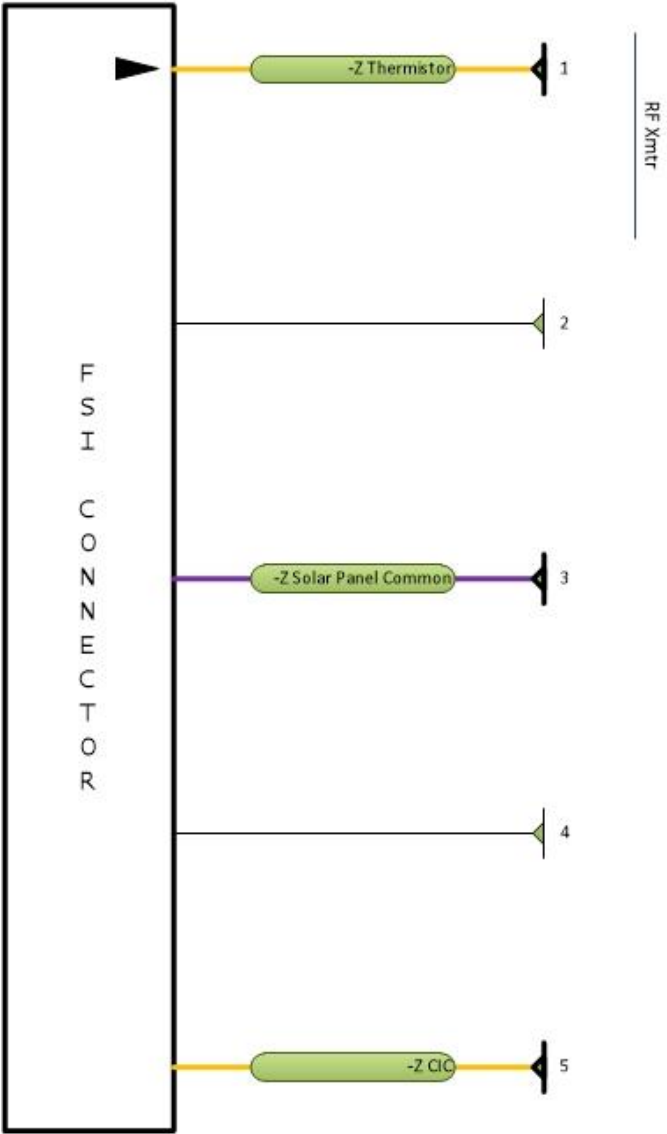
Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna $\approx$ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on -Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	N/C						
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC	Power	N/A	N/A	N/A	PSU	47

July 24, 2013
Version 1.3



Legend	
System	
ANTENNAS	Blue
EXPERIMENTS	Green
ALL	Purple
PSU/BATT	Orange
UMBILICAL	Yellow
RF	Red
In use	Triangle pointing right
Not in use	Triangle pointing left

Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.	
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.	
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.	
2.4.2	All satellite uplinks shall be in the 70 cm band of the amateur satellite service.	
2.4.5	All satellite frequencies shall be coordinated with the IARU.	
3.7.1	The satellite shall include an FM uplink receiver.	
3.7.2	The receiver shall have specifications as shown in Table 1.	
	Sensitivity	-120 dBm for 12 dB SINAD (min.)
	FM Deviation	5 kHz
	Audio Bandwidth	3 kHz
	Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)
3.8.3	The transmitter shall provide a means to prevent over modulation.	
3.9.1	The satellite shall provide an FM transponder via the RF uplink and RF downlink.	
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.	
3.10.1	The satellite shall collect telemetry data.	
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3.	
	Parameter Name	Description
	CELL V	Voltages of battery cells
	PANEL V	Voltages of solar panels
	TOTAL I	Total DC current out of power system
	PA I	DC current into RF power amp
	BATTERY T	Temperature of battery
	PANEL T	Temperatures of solar panels
	TX T	Temperature of RF transmitter card
	RX T	Temperature of RF receiver card
3.10.3	The measured parameters shall be sampled at least every 15 seconds.	
3.12.2	The commands received via the RF uplink shall not be repeated on the RF downlink.	
3.13.12	The RF uplink shall be monitored for commands in all modes.	



4.2 Initial Surge Current Limits

4.2.1 The RF Receiver design shall limit initial inrush current to 0.1 Amperes.

4.3 Volume Requirements Applicable to RF Receiver System

4.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

4.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.4 Interface Control Documents Applicable to RF Receiver System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

4.5 PCB Plating Requirements Applicable to RF Receiver System

4.5.1 ENIG then selective flash gold four mounting pads.

4.6 RF Receiver System PCB Bus Connections

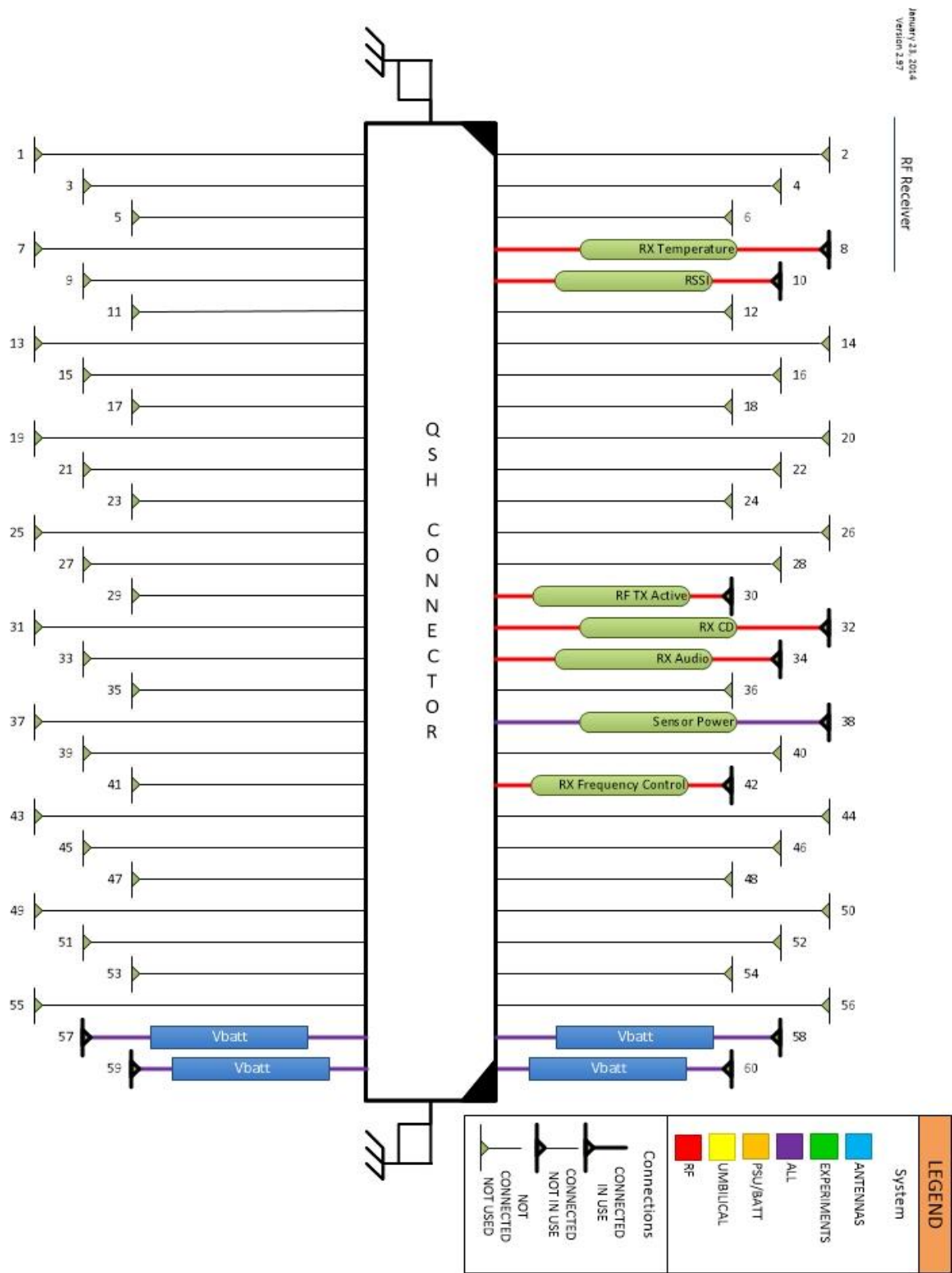


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.7 RF Receiver System PCB External Connections

4.7.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

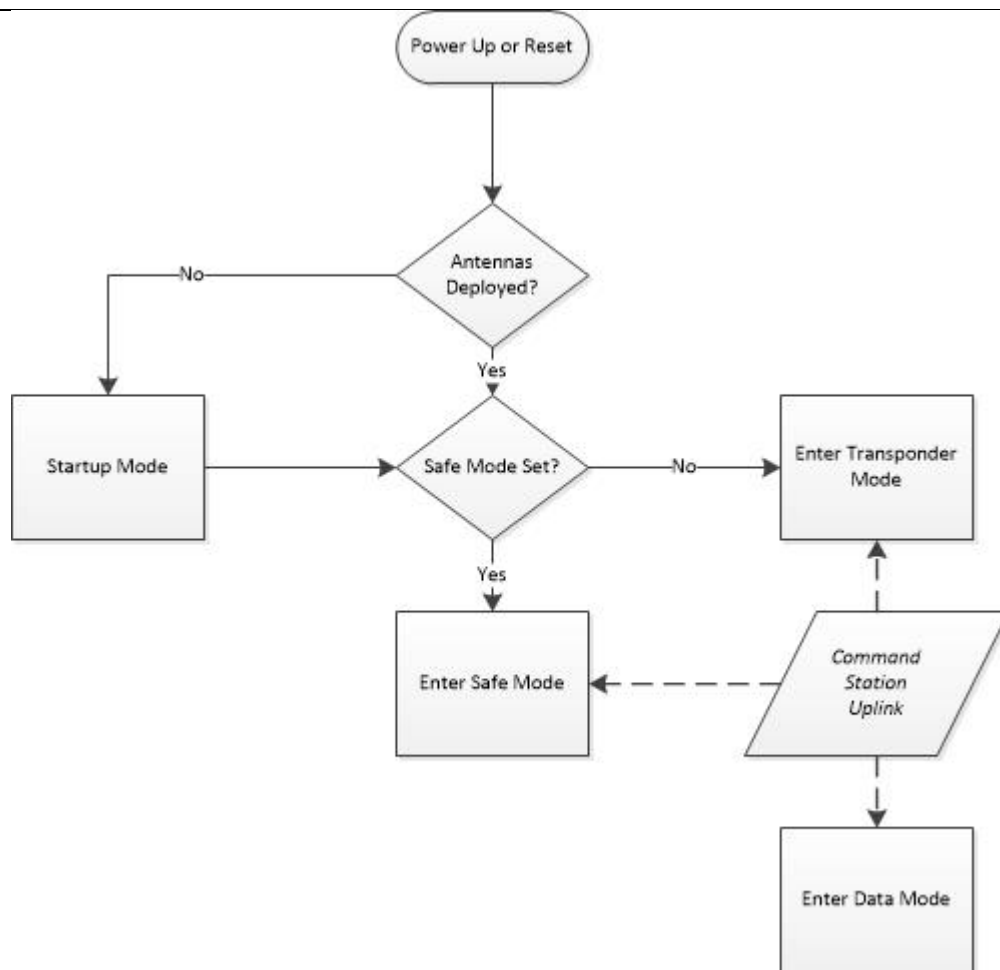
5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.2	The satellite shall include an umbilical port as per the CubeSat Design Specification.																		
3.4.3	The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.																		
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.																		
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.																		
3.9.2	In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.																		
3.9.3	In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.																		
3.9.4	In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (i.e. PTT-on).																		
3.9.5	In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.																		
3.9.6	In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.																		
3.9.7	In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
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3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		
3.10.4	The minimum and maximum values of each of the measured parameters shall be saved in non-																		



	volatile memory.																						
3.10.5	The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>UP TIME</td><td>Total seconds since avionics power-up or reset</td></tr> <tr> <td>SPIN</td><td>Satellite spin rate and direction</td></tr> </tbody> </table>	Parameter Name	Description	UP TIME	Total seconds since avionics power-up or reset	SPIN	Satellite spin rate and direction																
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3.10.6	A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.																						
3.11.1	The satellite shall send slow speed telemetry using FSK on the RF downlink.																						
3.11.2	The FSK shall use the frequency spectrum below the audible range.																						
3.11.3	The telemetry shall be transmitted simultaneously with any transponder communications.																						
3.11.4	The telemetry transmission shall include telemetry frames.																						
3.11.5	The telemetry transmission shall include experiment data.																						
3.12.1	The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.																						
3.12.3	The following commands shall be provided, as shown in Table 5. <table border="1"> <thead> <tr> <th>Command</th><th>Operation</th></tr> </thead> <tbody> <tr> <td>SAFE MODE</td><td>Enter Safe Mode</td></tr> <tr> <td>INHIBIT TX</td><td>Inhibit RF transmission</td></tr> <tr> <td>ENABLE TX</td><td>Enable RF transmission</td></tr> <tr> <td>IHU OFF</td><td>Power off IHU</td></tr> <tr> <td>IHU ON</td><td>Power on IHU</td></tr> <tr> <td>CLEAR</td><td>Clear stored telemetry</td></tr> <tr> <td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr> <tr> <td>DATA MODE</td><td>Enter Data Mode</td></tr> <tr> <td>ENABLE AUTO-SAFE</td><td>Enable Auto-Safe Mode</td></tr> <tr> <td>DISABLE AUTO-SAFE</td><td>Disable Auto-Safe Mode</td></tr> </tbody> </table>	Command	Operation	SAFE MODE	Enter Safe Mode	INHIBIT TX	Inhibit RF transmission	ENABLE TX	Enable RF transmission	IHU OFF	Power off IHU	IHU ON	Power on IHU	CLEAR	Clear stored telemetry	TRANSPONDER MODE	Enter Transponder Mode	DATA MODE	Enter Data Mode	ENABLE AUTO-SAFE	Enable Auto-Safe Mode	DISABLE AUTO-SAFE	Disable Auto-Safe Mode
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DISABLE AUTO-SAFE	Disable Auto-Safe Mode																						
3.12.4	A SAFE MODE command shall cause the satellite to enter the Safe Mode.																						
3.12.5	An INHIBIT TX command shall disable the RF transmitter.																						
3.12.6	An ENABLE TX command shall enable the RF transmitter.																						
3.12.7	An IHU OFF command shall cause the IHU System to power off.																						
3.12.8	An IHU ON command shall cause the IHU System to power on.																						
3.12.9	A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.																						
3.12.10	A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.																						

3.12.11	A DATA MODE command shall cause the satellite to enter the Data Mode.												
3.12.12	An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.												
3.12.13	A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.												
3.13.1	The satellite shall provide on-orbit operating modes as shown in Table 6.												
	<table><tr><th>Name</th><th>Description</th></tr><tr><td>Startup Mode</td><td>Wait 45 minutes and deploy antennas</td></tr><tr><td>Safe Mode</td><td>Wait 120 seconds then begin 10 second beacon sequence</td></tr><tr><td>Transponder Mode</td><td>FM transponder; PTT and low speed telemetry via IHU</td></tr><tr><td>Data Mode</td><td>FM transmitter; PTT and high speed telemetry via IHU</td></tr></table>	Name	Description	Startup Mode	Wait 45 minutes and deploy antennas	Safe Mode	Wait 120 seconds then begin 10 second beacon sequence	Transponder Mode	FM transponder; PTT and low speed telemetry via IHU	Data Mode	FM transmitter; PTT and high speed telemetry via IHU		
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3.13.2	The satellite shall transition between modes as shown in Figure 1.												
3.13.3	Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.												
3.13.4	An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.												



3.13.5	If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.
3.13.5.1	If the last state was Safe Mode the satellite shall enter Safe Mode
3.13.5.2	If the last state was not Safe Mode the satellite shall enter Transponder Mode.
3.13.6	If the antennas have not been deployed, the satellite shall enter the Startup Mode.
3.13.7	In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.
3.13.7.1	During the 50 minute wait the IHU shall flash a red LED.
3.13.7.2	During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.
3.13.7.3	After the antennas have been deployed the satellite shall enter Safe Mode.
3.13.8	In Transponder Mode, the transponder and the slow speed telemetry shall be active.
3.13.9	In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)
3.13.10	If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 30 minutes after having entered Data Mode.
3.13.11	In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.
3.13.11.1	The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.
3.13.12	The RF uplink shall be monitored for commands in all modes.



5.3 Initial Surge Current Limits

5.3.1 The IHU design shall limit initial inrush current to 0.1 Amperes.

5.4 Volume Requirements Applicable to IHU System

5.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

5.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.5 Interface Control Documents Applicable to IHU System

[AMSAT Fox-1 IHU to RF System Interface Control Document](#)

[AMSAT Fox-1 IHU to PSU Interface Control Document](#)

[AMSAT Fox-1 IHU to Battery Interface Control Document](#)

[AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document](#)

[AMSAT Fox-1 IHU to Experiment 1 Interface Control Document](#)

[AMSAT Fox-1 IHU to Experiment 4 Interface Control Document](#)

5.6 PCB Plating Requirements Applicable to IHU System

5.6.1 ENIG then selective flash gold four mounting pads.

5.7 Internal Housekeeping Unit (IHU) System PCB Bus Connections

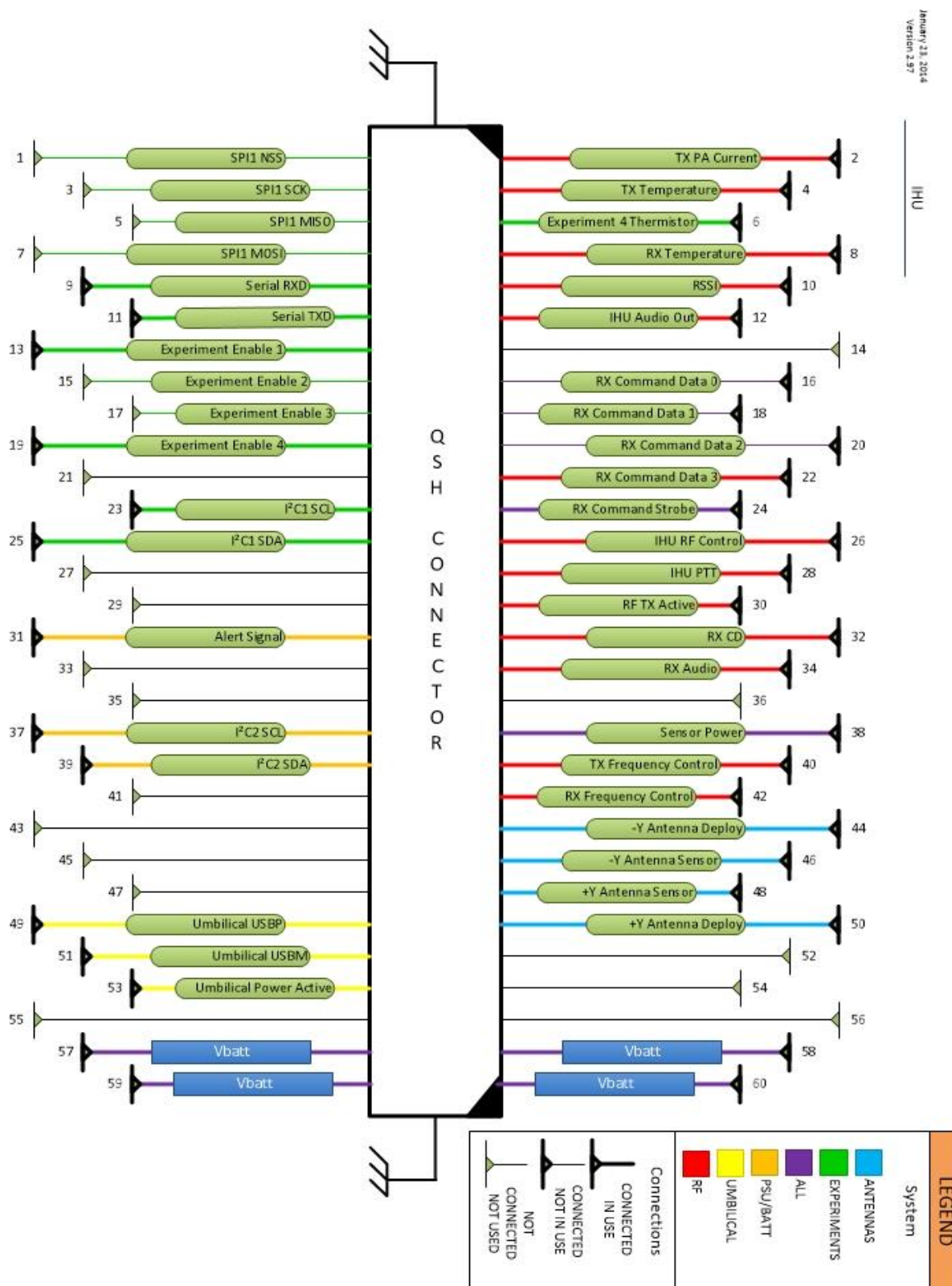


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.1	The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.																		
3.4.1	The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).																		
3.4.2	The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.																		
3.5.1	The satellite shall produce electrical power from sunlight.																		
3.5.2	The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.																		
3.5.3	The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.																		
3.5.4	The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.																		
3.6.1	The satellite shall provide DC power for experiment payloads.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
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TX T	Temperature of RF transmitter card																		
RX T	Temperature of RF receiver card																		
3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		
3.13.7.1	During the 45 minute wait the IHU shall flash a red LED.																		



6.2 Initial Surge Current Limits

6.2.1 The PSU design shall limit initial inrush current to 0.1 Amperes.

6.3 Volume Requirements Applicable to PSU System

6.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

6.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.4 Interface Control Documents Applicable to PSU System

[AMSAT Fox-1 IHU to PSU Interface Control Document](#)

6.5 PCB Plating Requirements Applicable to PSU System

6.5.1 ENIG then selective flash hard gold 30 micro-inch four mounting pads and four edge fingers.

6.6 Power Supply System (PSU) PCB Bus Connections

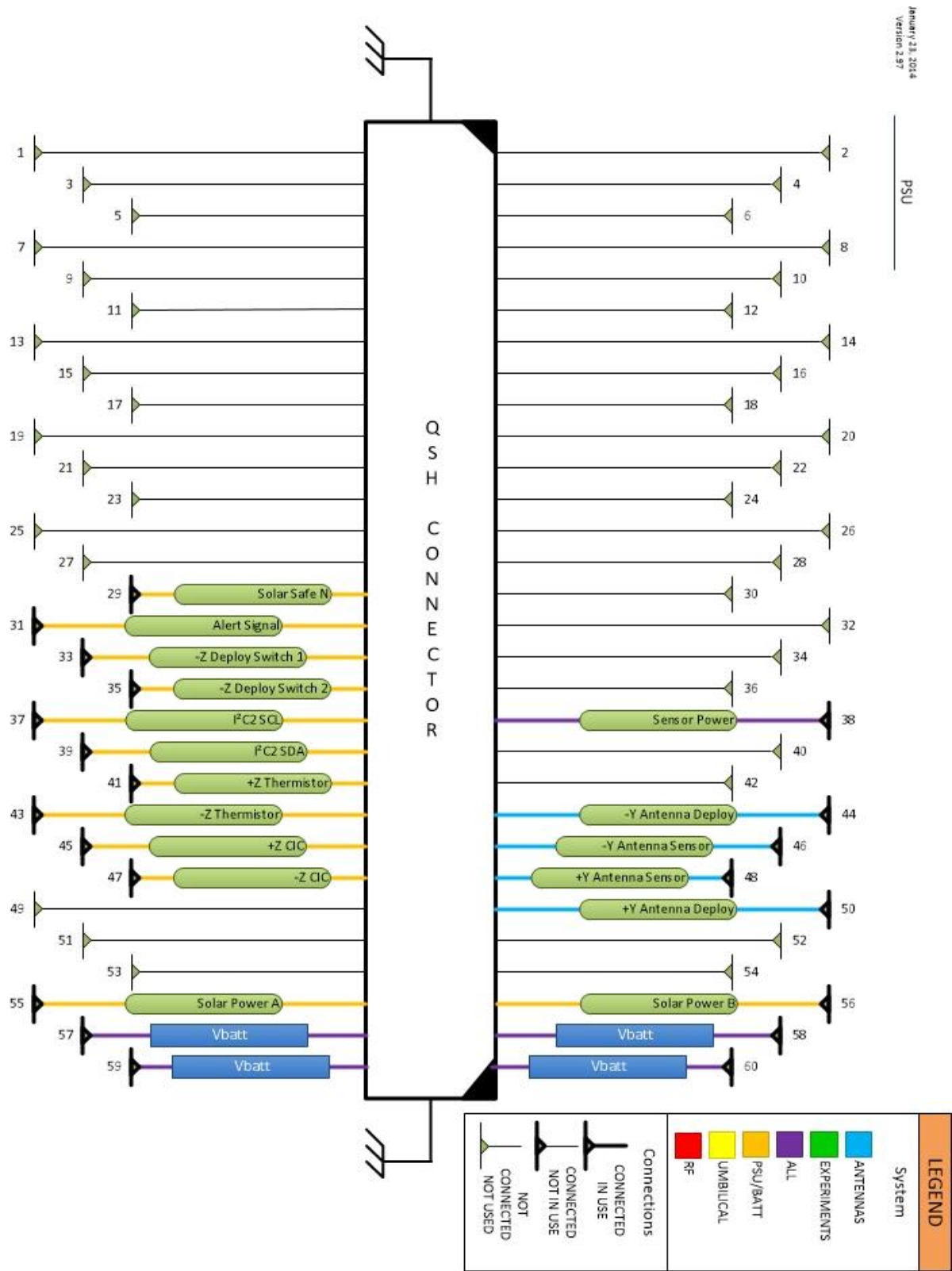


Figure 7: PSU Bus Connection Pin Assignments

6.7 Power Supply System (PSU) PCB External Connections

- 6.7.1** Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.7.1.1** 1 contact +X Solar Panel Thermistor
 - 6.7.1.2** 1 contact +X Solar Panel CIC +
 - 6.7.1.3** 1 contact common or - for above two connections
- 6.7.2** Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.7.2.1** 1 contact -X Solar Panel Thermistor
 - 6.7.2.2** 1 contact -X Solar Panel CIC +
 - 6.7.2.3** 1 contact common or - for above two connections
- 6.7.3** Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.7.3.1** 1 contact +Y Solar Panel Thermistor
 - 6.7.3.2** 1 contact +Y Solar Panel CIC +
 - 6.7.3.3** 1 contact TX Antenna Deploy
 - 6.7.3.4** 1 contact TX Antenna Sensor
 - 6.7.3.5** 1 contact common or - for above connections
- 6.7.4** Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
 - 6.7.4.1** 1 contact -Y Solar Panel Thermistor
 - 6.7.4.2** 1 contact -Y Solar Panel CIC +
 - 6.7.4.3** 1 contact RX Antenna Deploy
 - 6.7.4.4** 1 contact RX Antenna Sensor
 - 6.7.4.5** 1 contact common or - for above connections
- 6.7.5** All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

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Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

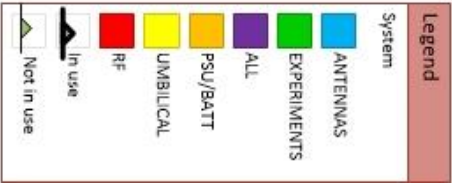
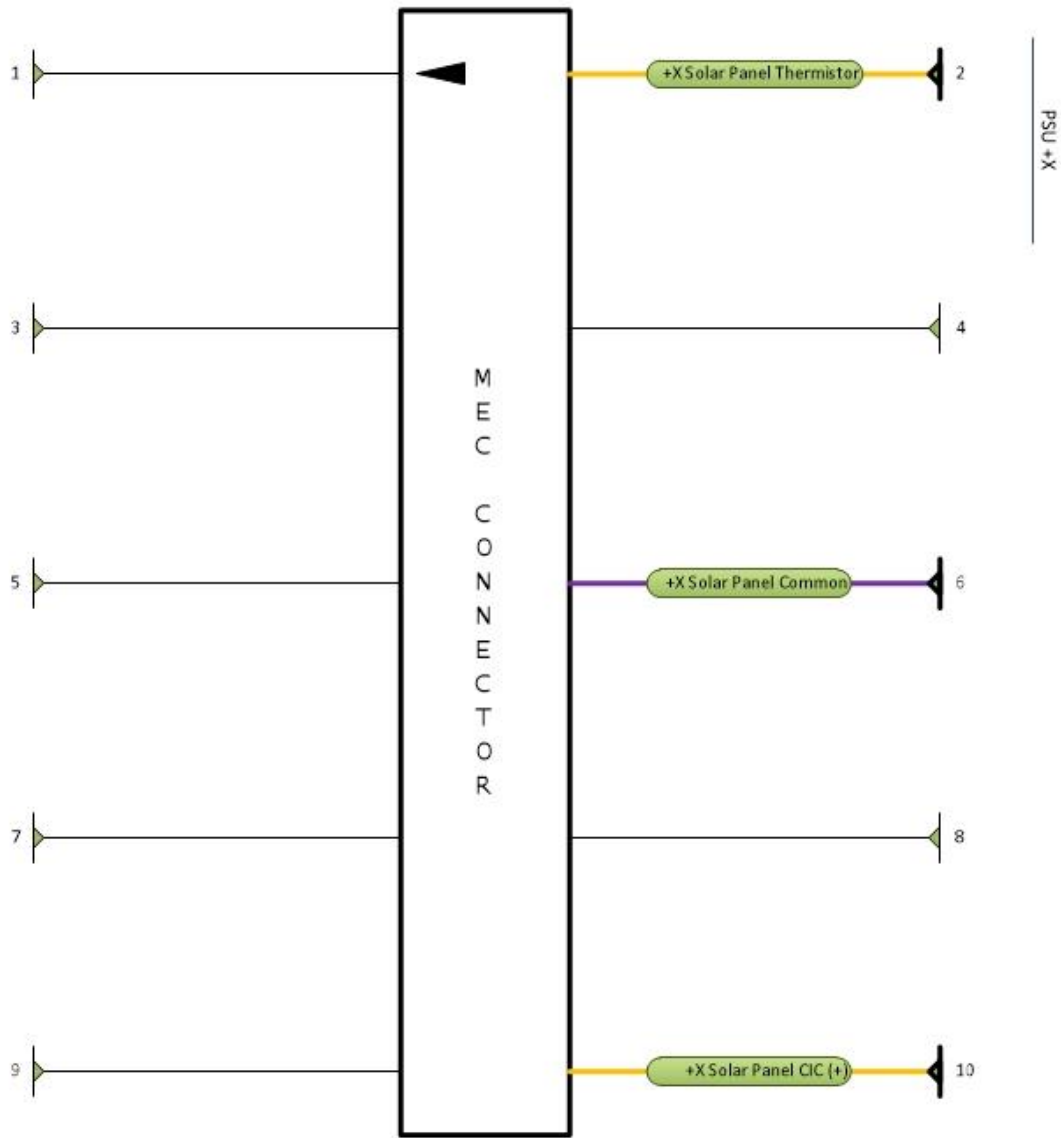


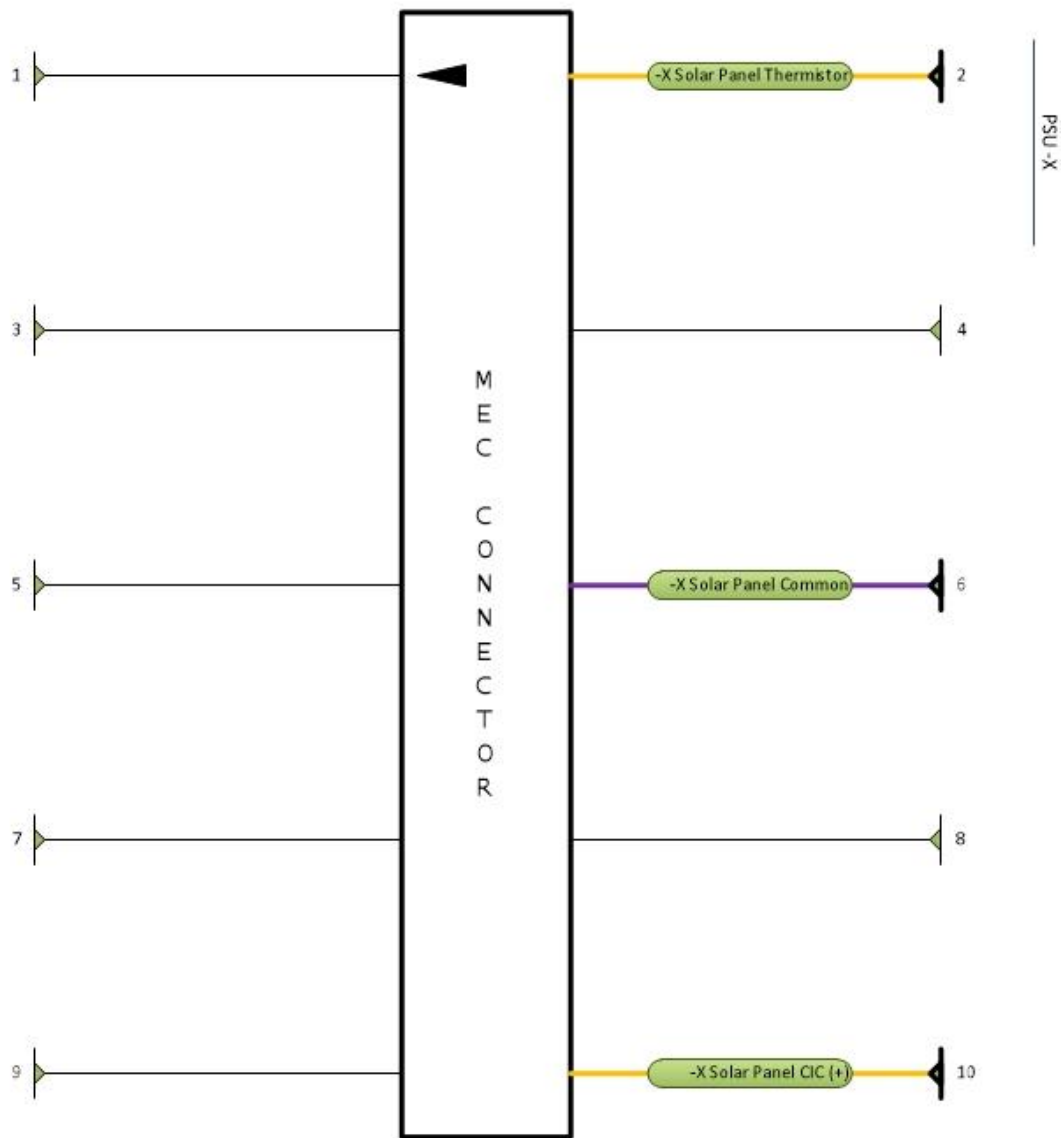
Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

AMSAT Fox-1
Avionics System Design Specification



Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A



Legend	
System	
ANTENNAS	Blue
EXPERIMENTS	Green
ALL	Purple
PSU/BATT	Yellow
UMBILICAL	Red
RF	Black
In use	Triangle
Not in use	Circle

Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

AMSAT Fox-1
Avionics System Design Specification



Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	48
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	50
9	N/C					
10	+Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

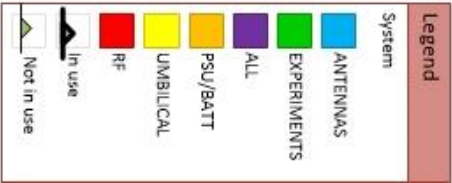
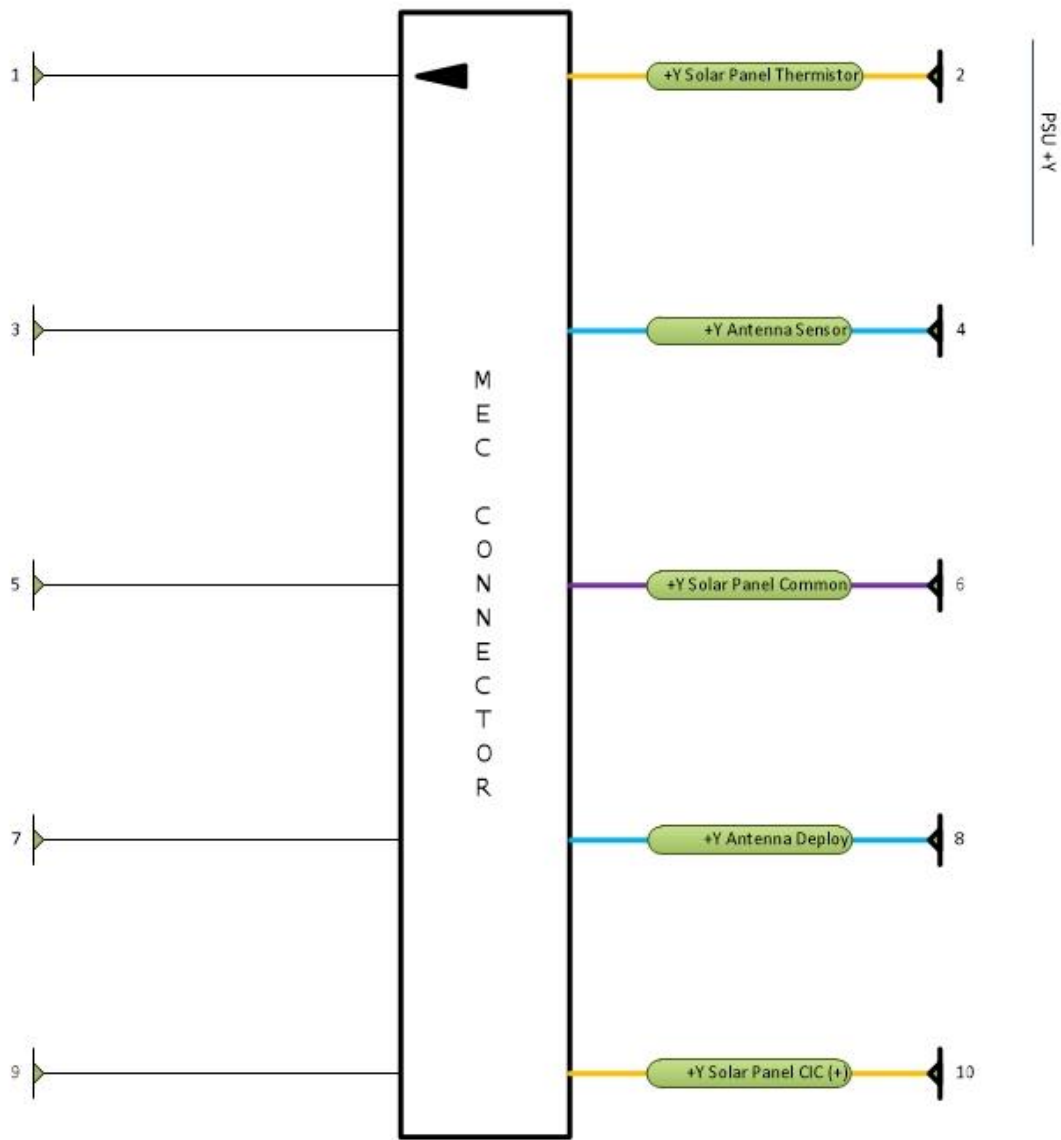


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

AMSAT Fox-1
Avionics System Design Specification



Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	46
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	44
9	N/C					
10	-Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

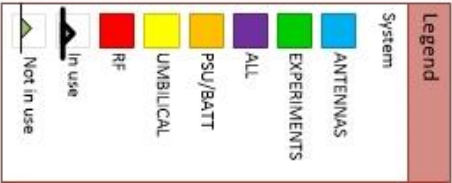
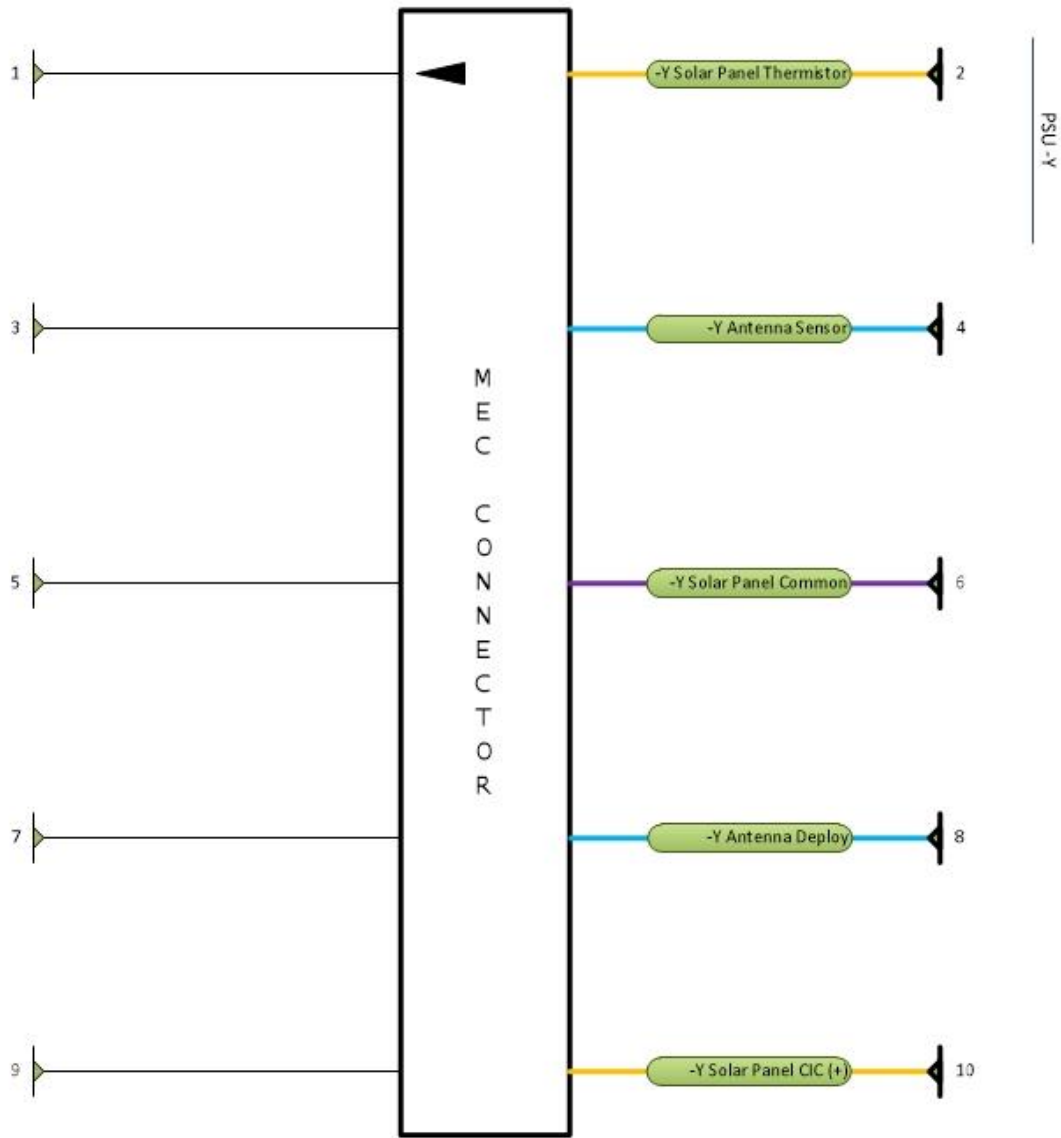


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 System Requirements Applicable to Battery PCB 1 System (BATT1)

2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.																		
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.																		
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.																		
3.3.1	The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.																		
3.4.1	The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).																		
3.4.2	The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.																		
3.5.3	The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.																		
3.5.4	The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.																		
3.10.1	The satellite shall collect telemetry data.																		
3.10.2	The telemetry data shall include at a minimum, measured parameters as shown in Table 3. <table border="1"> <thead> <tr> <th>Parameter Name</th><th>Description</th></tr> </thead> <tbody> <tr> <td>CELL V</td><td>Voltages of battery cells</td></tr> <tr> <td>PANEL V</td><td>Voltages of solar panels</td></tr> <tr> <td>TOTAL I</td><td>Total DC current out of power system</td></tr> <tr> <td>PA I</td><td>DC current into RF power amp</td></tr> <tr> <td>BATTERY T</td><td>Temperature of battery</td></tr> <tr> <td>PANEL T</td><td>Temperatures of solar panels</td></tr> <tr> <td>TX T</td><td>Temperature of RF transmitter card</td></tr> <tr> <td>RX T</td><td>Temperature of RF receiver card</td></tr> </tbody> </table>	Parameter Name	Description	CELL V	Voltages of battery cells	PANEL V	Voltages of solar panels	TOTAL I	Total DC current out of power system	PA I	DC current into RF power amp	BATTERY T	Temperature of battery	PANEL T	Temperatures of solar panels	TX T	Temperature of RF transmitter card	RX T	Temperature of RF receiver card
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PANEL T	Temperatures of solar panels																		
TX T	Temperature of RF transmitter card																		
RX T	Temperature of RF receiver card																		
3.10.3	The measured parameters shall be sampled at least every 15 seconds.																		



7.2 Volume Requirements Applicable to Battery PCB 1 System

7.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.3 Interface Control Documents Applicable to Battery PCB 1 System

[AMSAT Fox-1 IHU to Battery Interface Control Document](#)

7.4 PCB Plating Requirements Applicable to Battery PCB 1 System

7.4.1 ENIG then selective flash gold four mounting pads.

7.5 Battery PCB 1 System Bus Connections

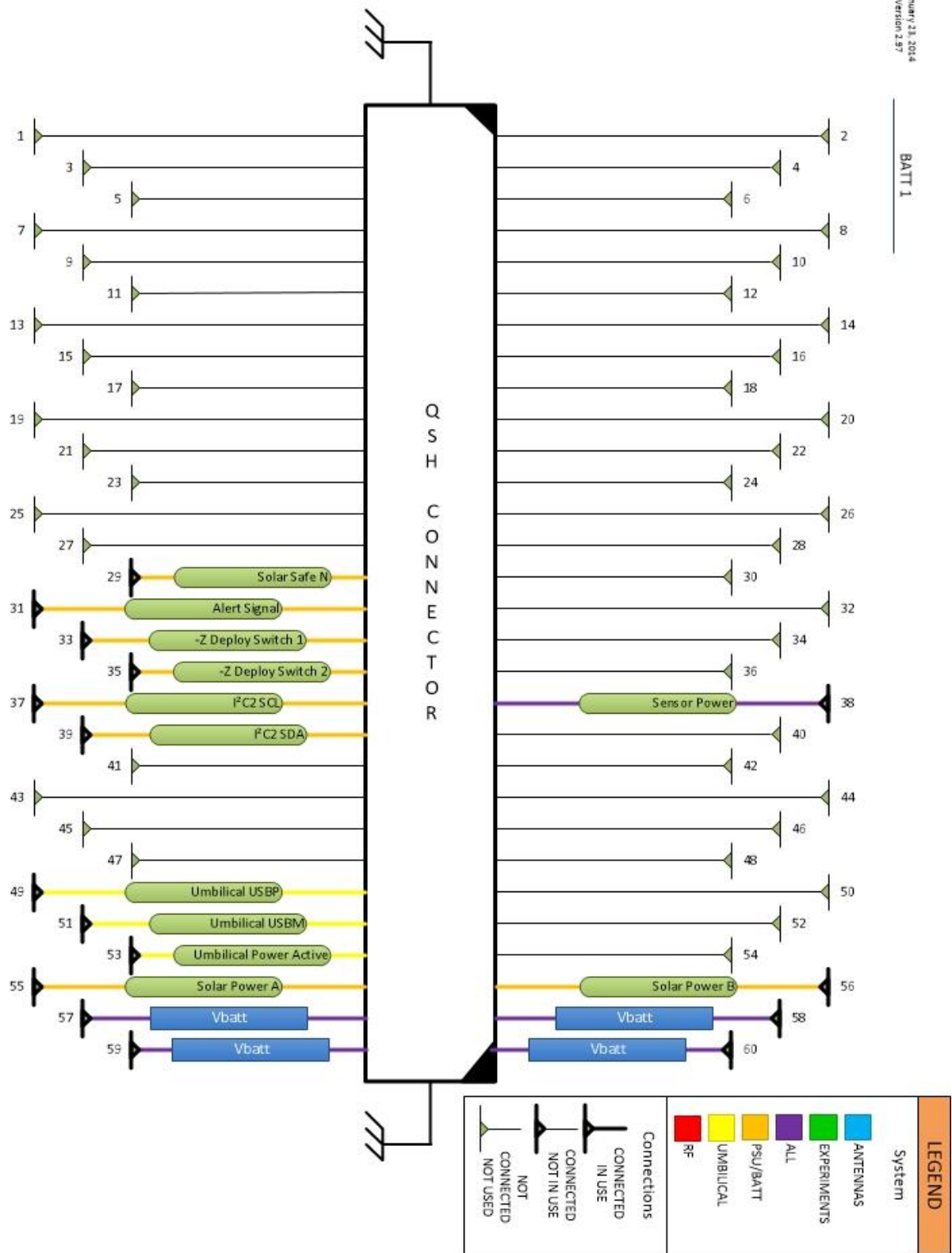


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.6 Battery PCB 1 System External Connections

7.6.1 Umbilical as USB mini type B receptacle

7.6.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
USB 1	USB +5 VDC	Analog	5 VDC	USB CONNECTOR	N/A	N/A
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	Solar Safe N	Analog	N/A	3.5mm N.O. TS jack	N/A	40

*When external supply is connected to USB port

7.7 Battery PCB 2 System Bus Connections

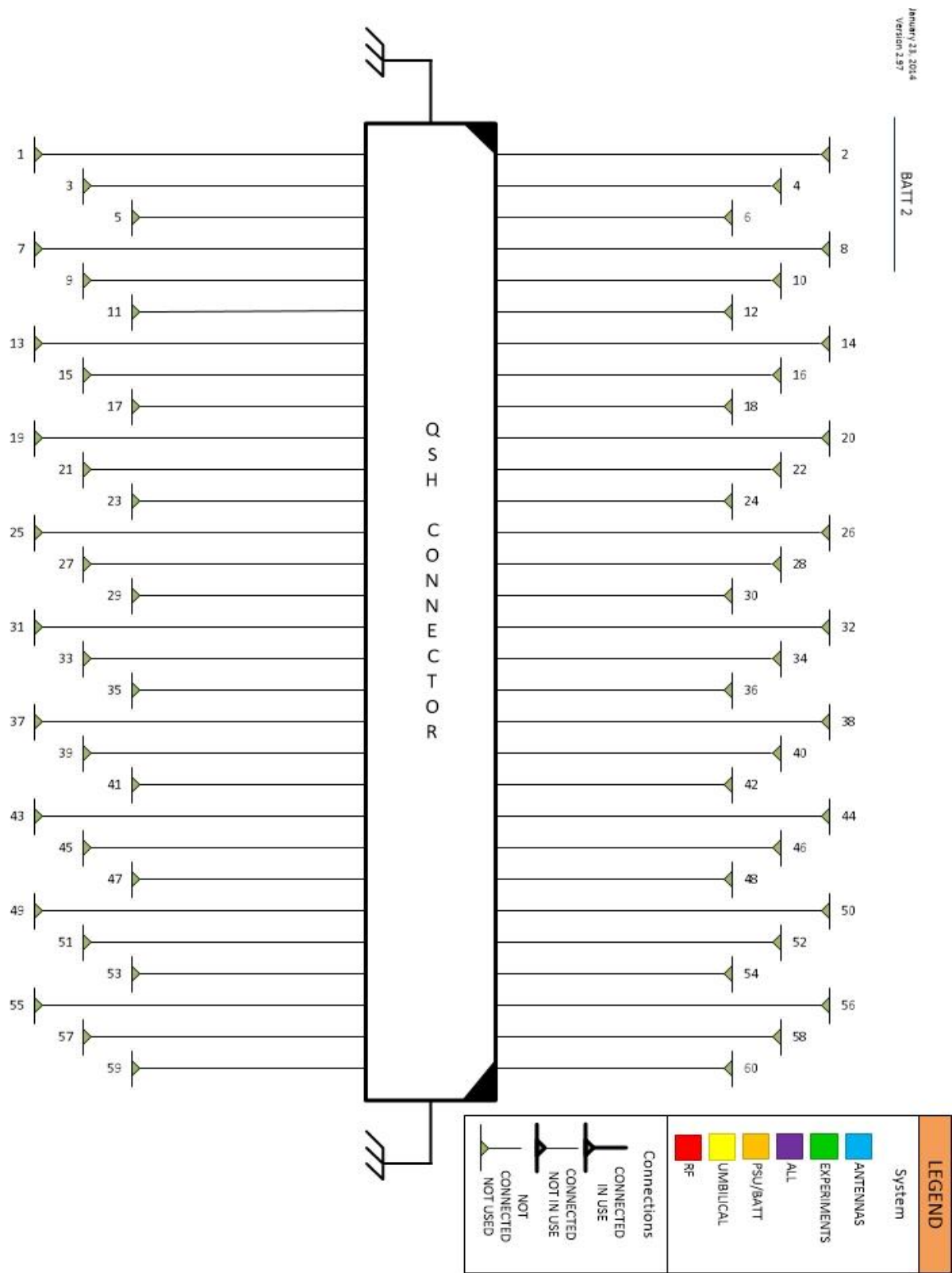


Figure 13: Battery 2 Bus Connection Pin Assignments



8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4	The satellite shall provide mass for an experiment payload up to 100 g.
2.1.5	The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.6.1	The satellite shall provide DC power for experiment payloads.
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.

8.2 Initial Surge Current Limits

8.2.1 All Experiment designs shall limit initial inrush current to 0.1 Amperes.

8.3 Volume Requirements Applicable to Experiment Payload System 1

8.3.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the -Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Interface Control Documents Applicable to Experiment 1 Payload System

[AMSAT Fox-1 IHU to Experiment 1 Interface Control Document](#)

8.5 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.5.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

8.5.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.6 Volume Requirements Applicable to Experiment System 4

8.6.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the -Z surface of the PC board.

8.6.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.7 Interface Control Documents Applicable to Experiment 4 Payload System

[AMSAT Fox-1 IHU to Experiment 4 Interface Control Document](#)

8.8 PCB Plating Requirements Applicable to Experiment 1 Payload System

8.8.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.9 PCB Plating Requirements Applicable to Experiment 2 Payload System

8.9.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.10 PCB Plating Requirements Applicable to Experiment 3 Payload System

8.10.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.11 PCB Plating Requirements Applicable to Experiment 4 Payload System

8.11.1 ENIG then selective flash gold four mounting pads..

8.12 Experiment Payload 1 Systems PCB Bus Connections

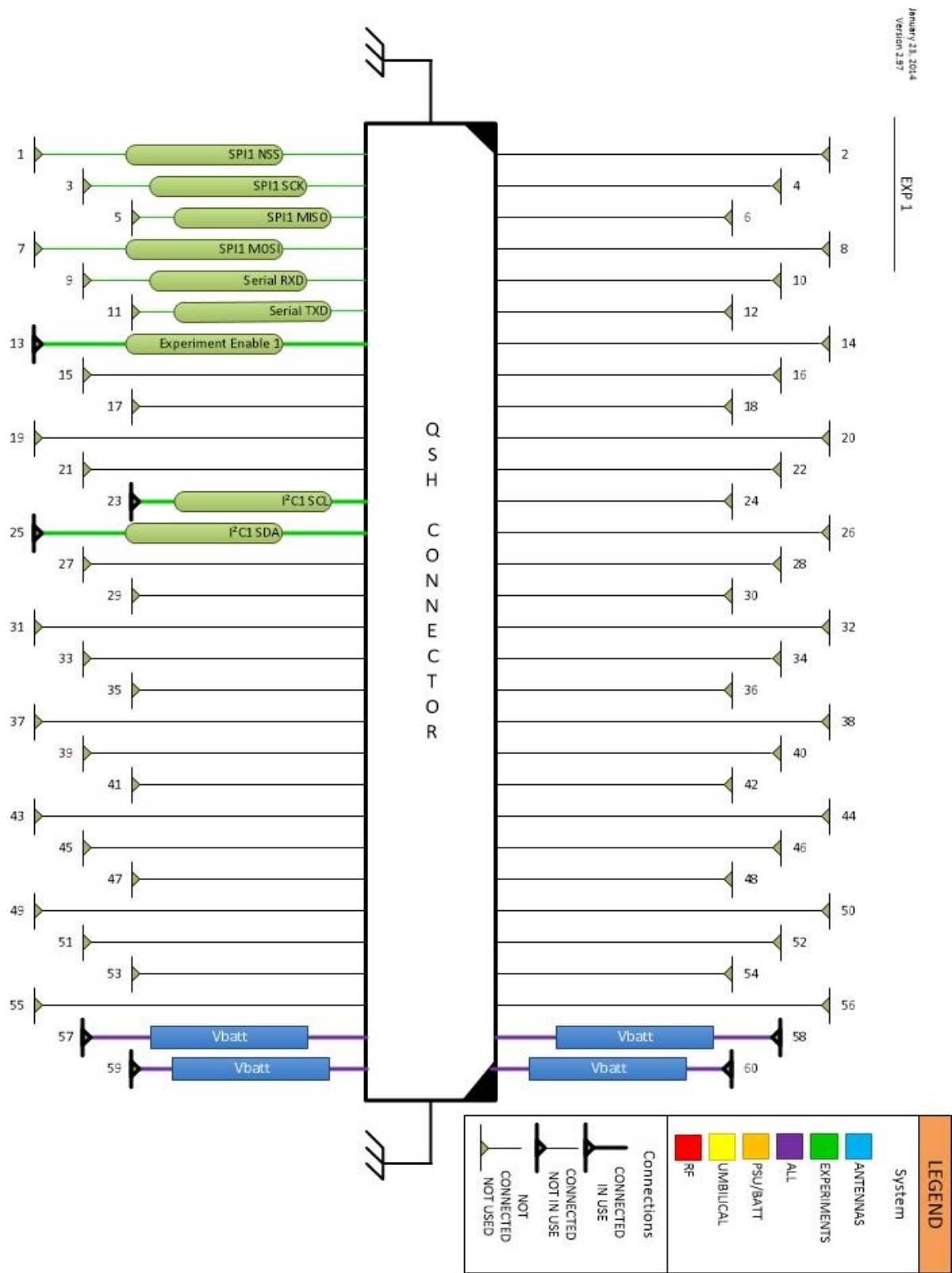


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.13 Experiment Payload 4 System PCB Bus Connections

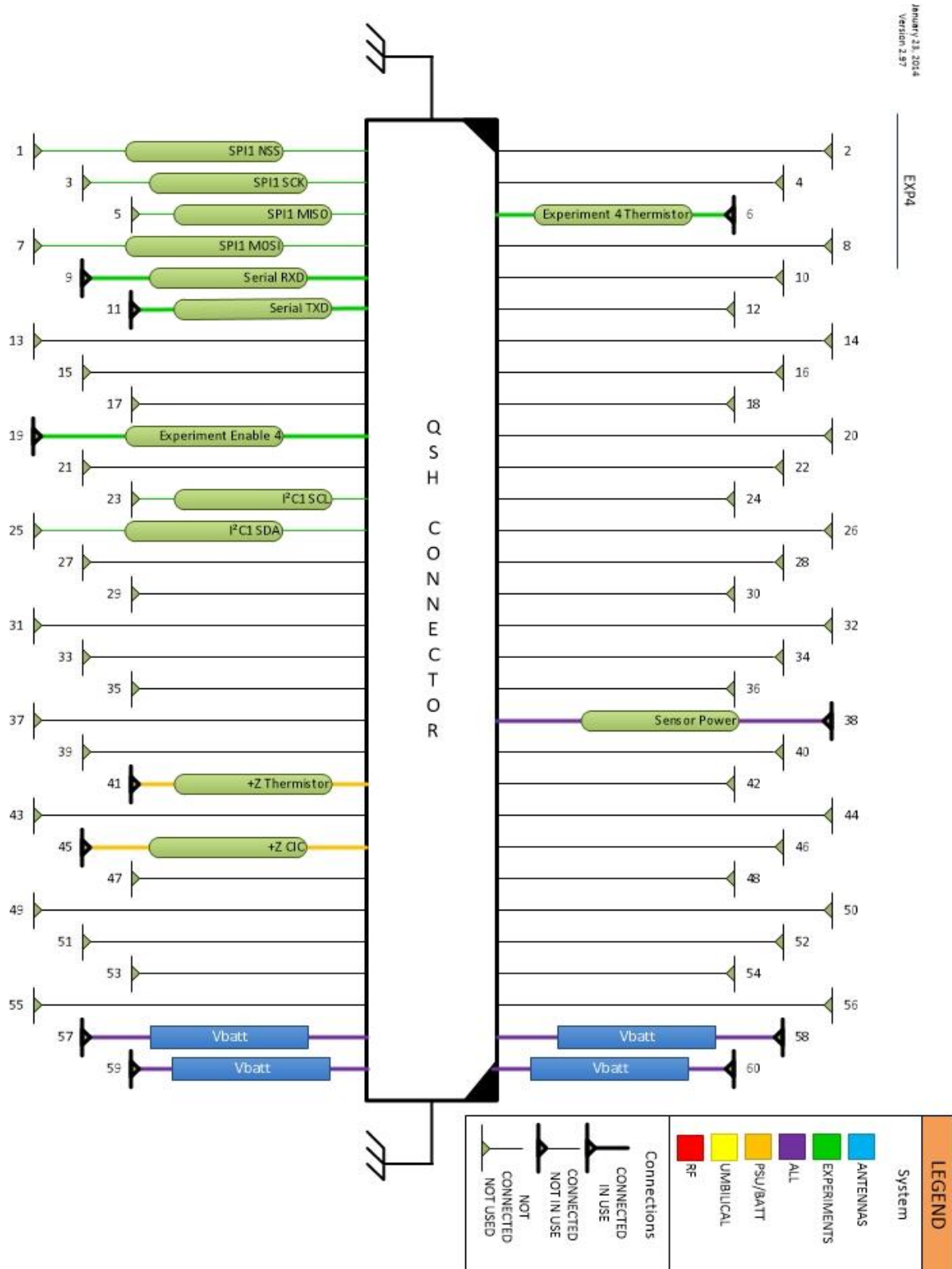


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.14 Experiment Payload 4 System PCB External Connections

8.14.1 Three connections using Samtec FSI-105-06-L-S-AD connector

8.14.1.1 1 contact +Z Solar Panel Thermistor

8.14.1.2 1 contact +Z Solar Panel CIC +

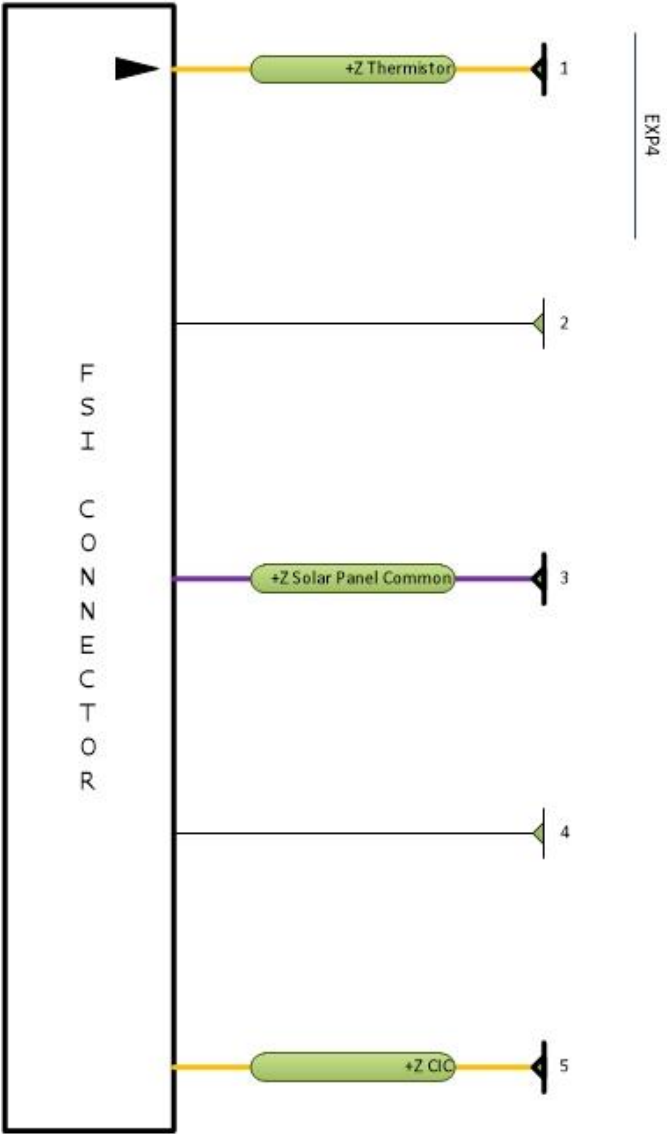
8.14.1.3 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC	Power	N/A	N/A	N/A	PSU	45



July 24, 2013
Version 1.3



Legend	
System	
ANTENNAS	Blue
EXPERIMENTS	Green
ALL	Purple
PSU/BATT	Orange
UMBILICAL	Yellow
RF	Red
In use	Black triangle pointing right
Not in use	Black triangle pointing left

Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD
Connection Pin Assignments

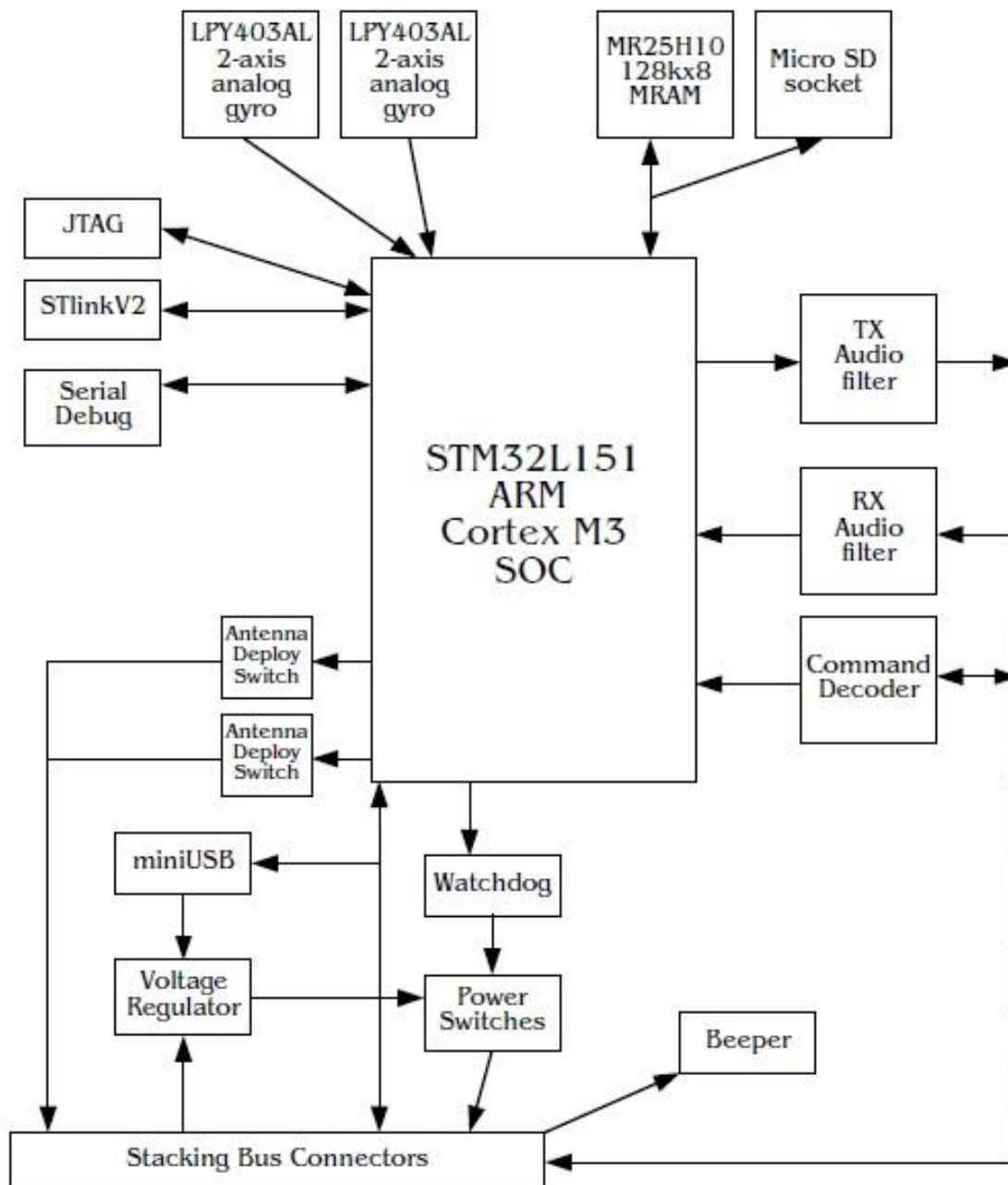
9 System Block Diagrams Reference

9.1 IHU System

Fox-1 IHU Block Diagram

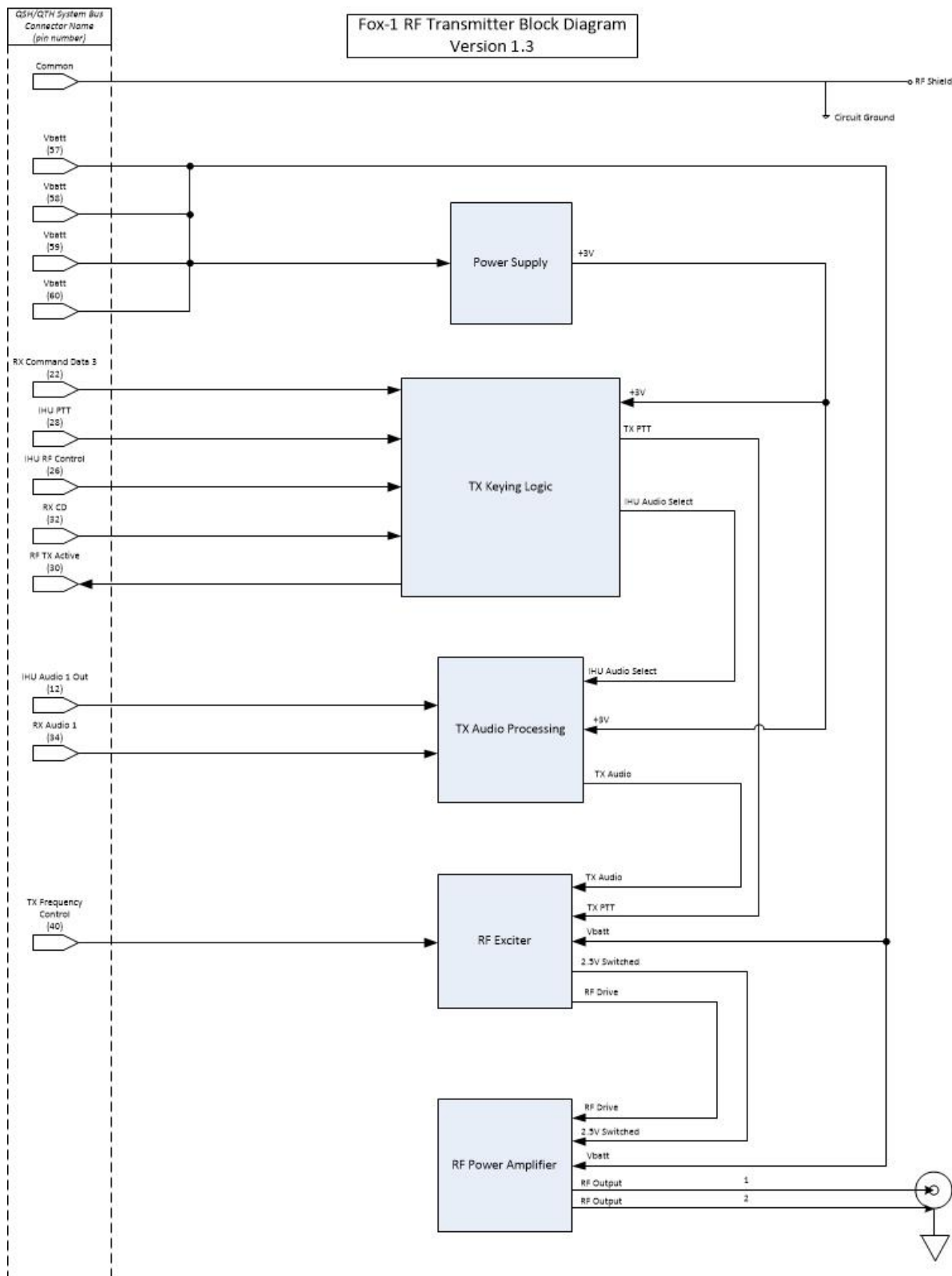
©Bdale Garbee, KB0G

Last updated 15 October 2013

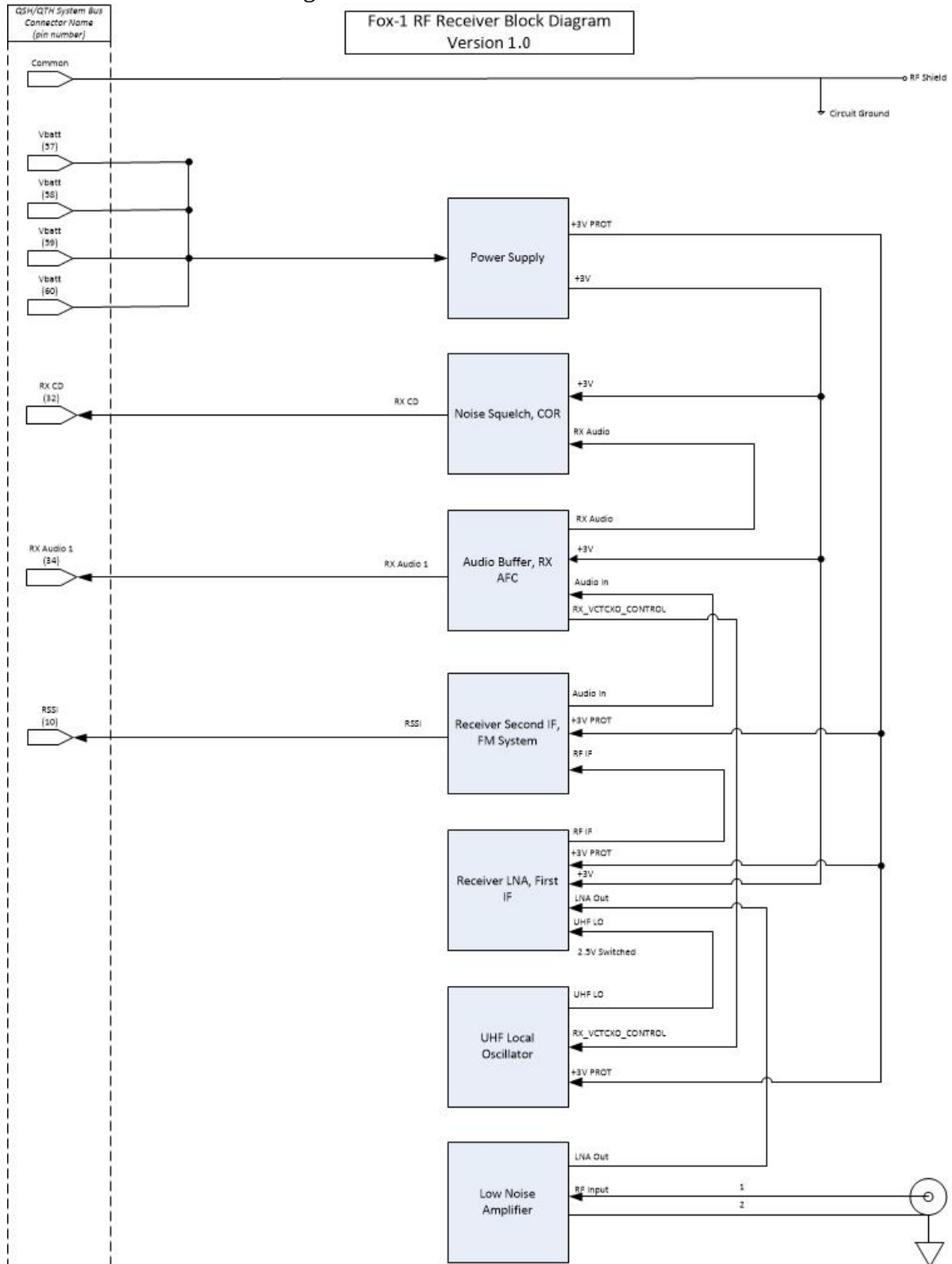


9.2 RF System

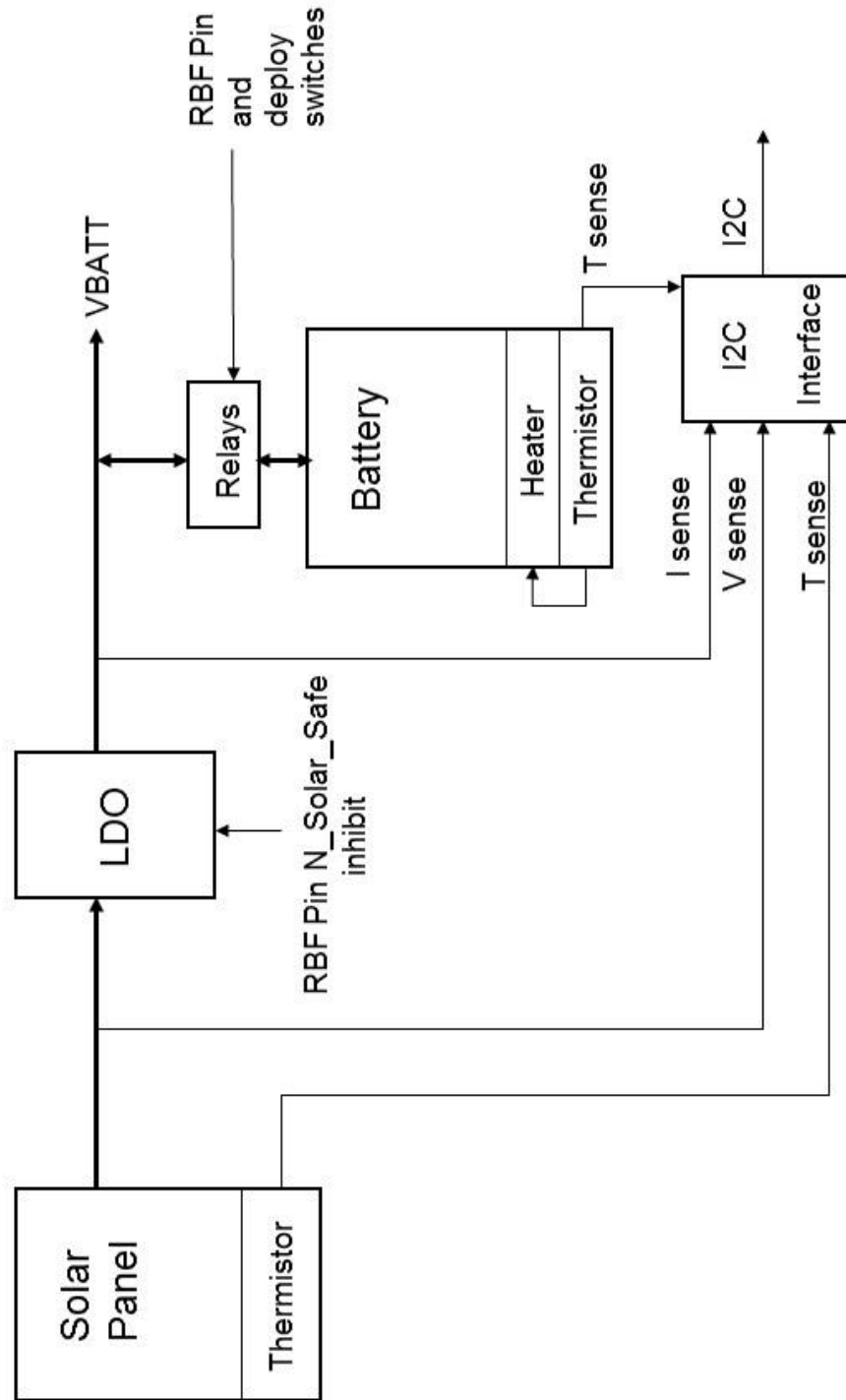
9.2.1 RF Transmitter Block Diagram



9.2.2 RF Receiver Block Diagram



9.3 PSU System





10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors

10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board

10.1.3 QSH connector shall be mounted on the –Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 [Samtec QSH](#)

10.2.2 [Samtec QTH](#)

10.2.3 [Samtec QxH High Speed Characterization Report](#)

10.2.4 [Samtec QxH Single Ended Channel Properties](#)

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels

10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

10.4.1 [Samtec MEC1](#)

10.4.2 [Samtec MEC1 Qualification Testing](#)

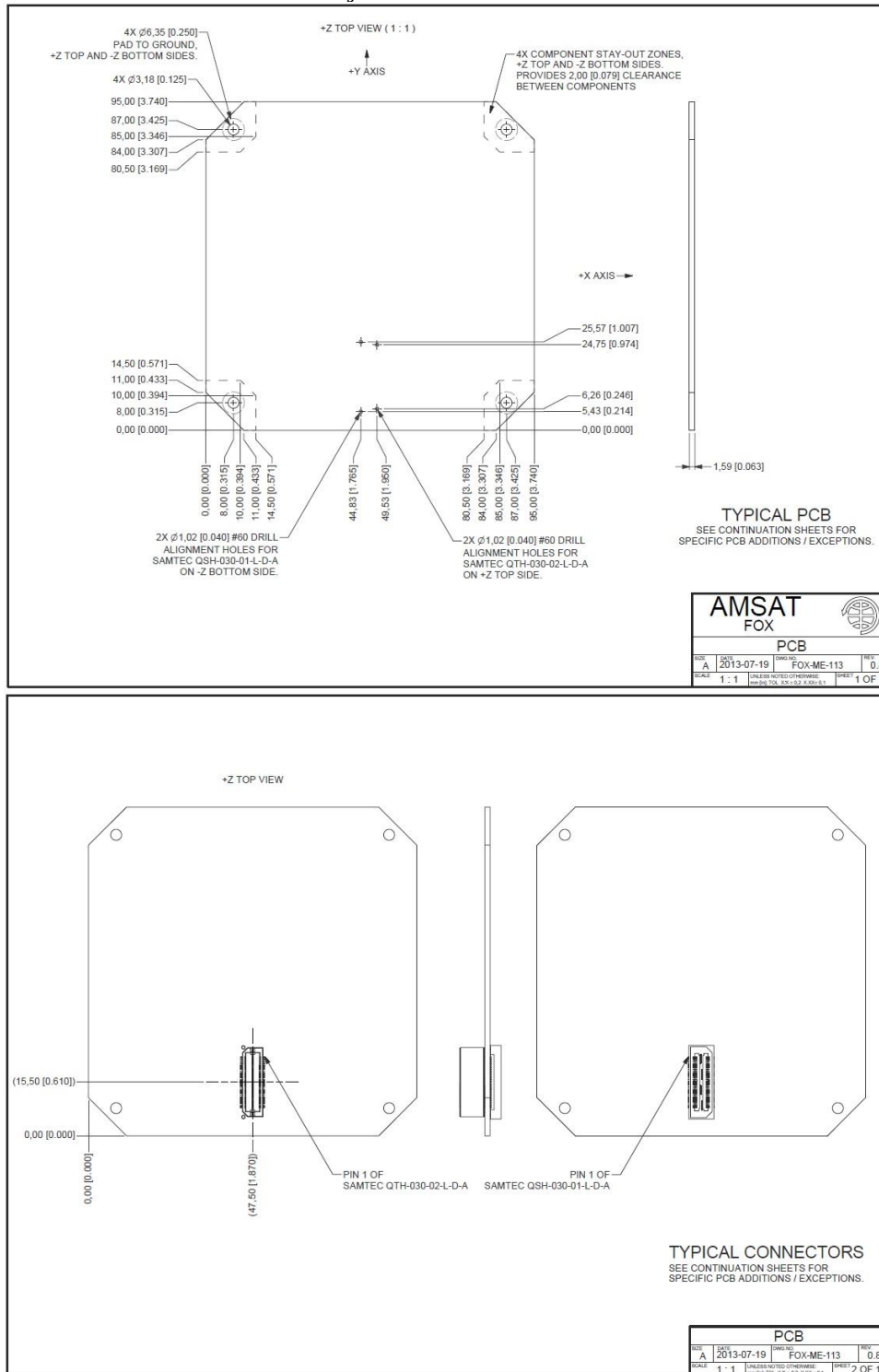
10.4.3 [Samtec FSI](#)

10.5 PCB Connector Layout Documentation

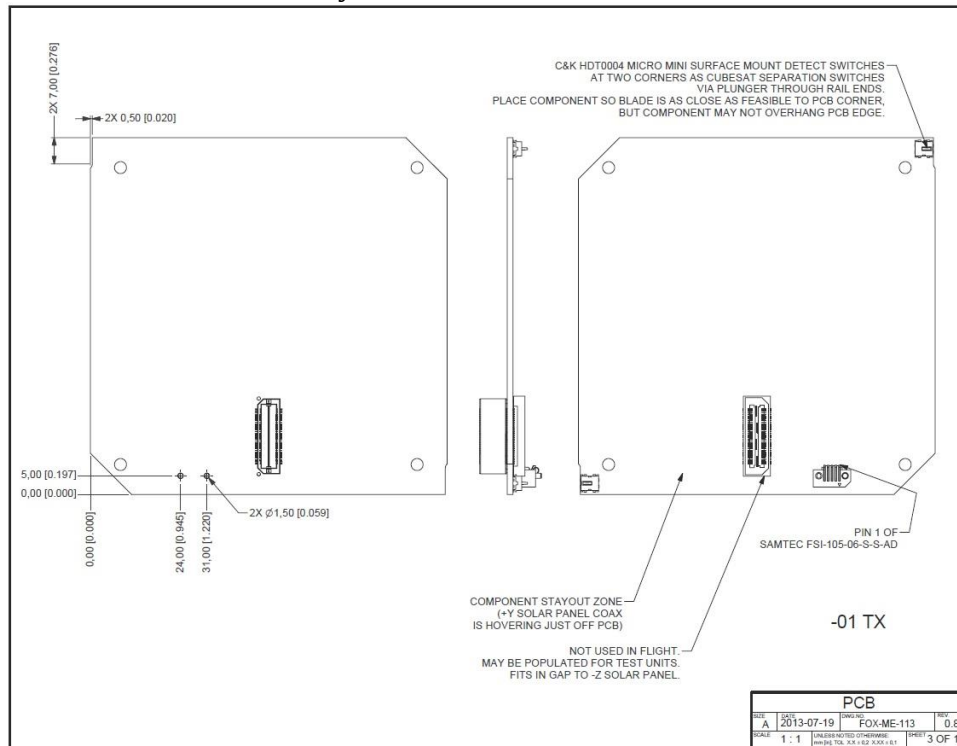
10.5.1 [FOX-ME-113_PCB.pdf](#)

10.6 Systems PCB Connector Layout

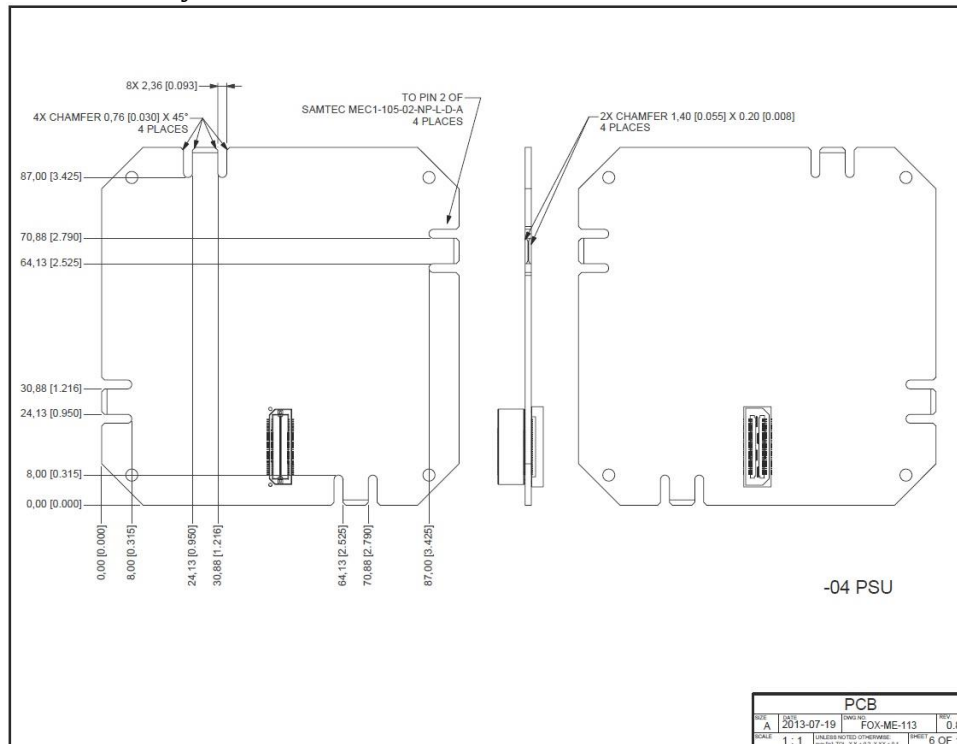
10.6.1 Common to All Systems



10.6.2 RF Transmitter System

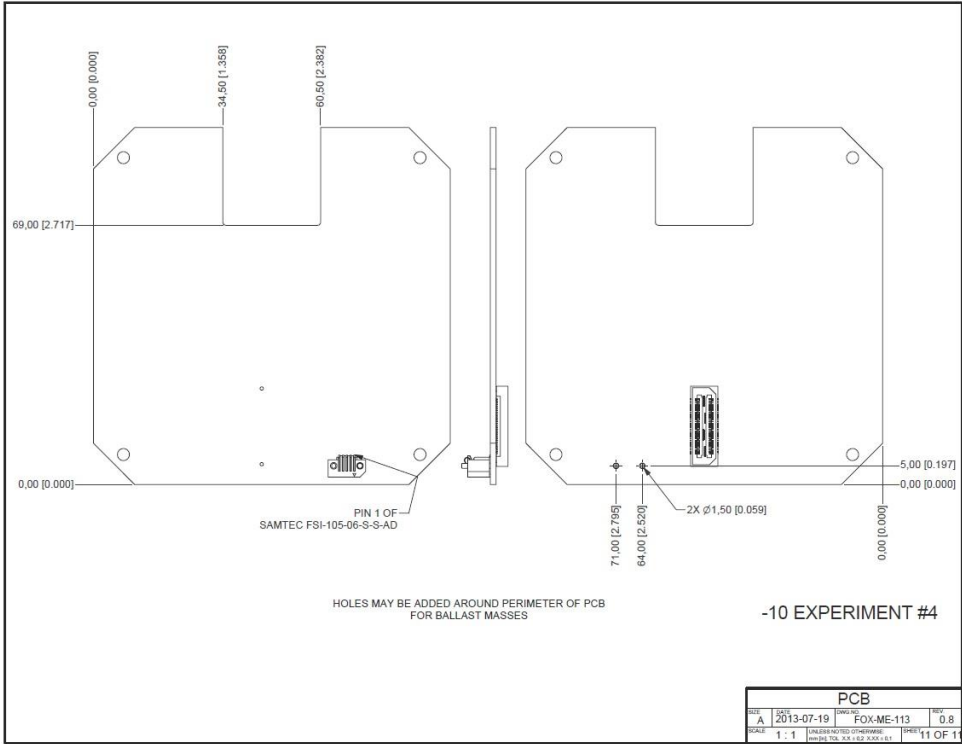


10.6.3 PSU System





10.6.4 Experiment 4 System



Date: November 18, 2013

Version: Version 2.06

AMSAT Fox-1

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT Fox-1 System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version
November 7, 2012	1.01	Added BATT CPU Temperature
December 27, 2012	1.10	Add Battery Groups Temperature, change from Bytes to Bits in Message Header Block, Message Data Block, Message Data
January 2, 2013	1.11	Field sizes back to bytes account I ² C specifications
February 7, 2013	1.12	Fix typo on 3.3.1.1
August 13, 2013	2.00	Updated for TI ADS 7828 replacing STM32L, straight I2C query/answer from IHU now for 8 channels of data.
August 22, 2013	2.01	Correct Battery Pair Temperature nomenclature
August 22, 2013	2.02	Update I ² C speed to 10 kHz
September 17, 2013	2.03	Fix formatting error that hid requirement 2.2.2, change type format to exclude code type, add Min/Max Values
November 7, 2013	2.04	Add battery voltage scaling in Table 1
November 7, 2013	2.05	Add verbiage about power bus voltage on Battery Pair C to Table 1
November 18, 2013	2.06	Revise battery voltage scale verbiage in Table 1, add raw value notation to BATT PCB Temp

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Texas Instruments SBAS181C – NOVEMBER 2001 - REVISED MARCH 2005

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send the data for a specific channel.

2.1.2.2 The BATT1 shall send that specific channel data.

2.1.3 The IHU shall test for the presence of the BATT1 system.

2.1.3.1 If the presence of the BATT1 system is not detected, the IHU shall not poll the system for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 The ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 The ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 The ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The BATT1 I²C 7 bit address shall be 0x48.

3 Data Requirements

3.1 Measured Values

3.1.1 The measured data fields and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
BATT I	0	Unsigned	0x00	0xFFFF	Battery current raw value
BATT A V	1	Unsigned	0x00	0xFFFF	Battery pair A voltage raw value (0-2.5V scale)
BATT B V	2	Unsigned	0x00	0xFFFF	Battery pairs A+B voltage raw value (0-3.3V scale)
BATT C V	3	Unsigned	0x00	0xFFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)
BATT A T	4	Unsigned	0x00	0xFFFF	Battery pair A temperature raw value
BATT B T	5	Unsigned	0x00	0xFFFF	Battery pair B temperature raw value
BATT C T	6	Unsigned	0x00	0xFFFF	Battery pair C temperature raw value
BATT PCB Temperature	7	Unsigned	0x00	0xFFFF	Temperature of BATT card raw value

3.1.2 Measurements shall be in relation to the 2.5 VDC internal voltage reference of the ADS 7828.

3.1.3 The IHU shall poll each channel in channel number order.

Date: June 11, 2014
Version: Version 2.21

AMSAT Fox-1

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT Fox-1 System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I ² C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly
November 7, 2012	1.04	Added PSU CPU Temperature
December 27, 2012	1.10	Change from Bytes to Bits in Message Header Block, Message Data Block, Message Data (to allow for 12 bit ADC values)
January 2, 2013	1.11	Field sizes back to bytes account I ² C specifications
February 7, 2013	1.12	Correct typo in 3.3.1.1
August 22, 2013	1.13	Remove TOTAL I from Data block
August 22, 2013	1.14	Update I ² C speed to 10 kHz
October 4, 2013	2.00	Rework to eliminate STM32L and replace with ADS7828s
November 18, 2013	2.01	Change telemetry sample rate in 2.2.1 to 4 seconds
April 21, 2014	2.1	Table 1 and Table 2 redone to use actual connections from PSU construction, 3.1.3 changed to show use of regulated Sensor Power source as 7828 voltage reference
June 10, 2014	2.2	Added PSU Output Current to Table 2
June 11, 2014	2.21	Swap Device 1 and Device 2 addresses to account for construction error

DATE	VERSION	SUMMARY
June 30, 2014	2.22	Modify 2.2.3 to command OFF rather than ON account internal reference not used on actual hardware build

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send the data for a specific Device and channel.

2.1.2.2 The PSU shall send that specific Device and channel data.

2.1.3 The IHU shall test for the presence both PSU system Devices.

2.1.4 The IHU shall only poll the PSU system Device(s) present, for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data every 4 seconds.

2.2.2 For both Devices the ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 For both Devices the ADS 7820 Internal Reference shall always be commanded off (PD-1 bit = 0).

2.2.4 TFor both Devices the ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The PSU system Device 1 I²C 7 bit address shall be 0x4A.

2.3.4 The PSU system Device 2 I²C 7 bit address shall be 0x49.

3 Message Content Requirements

3.1 Measured Values

3.1.1 The measured data fields for Device 1 and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
+X PANEL V	0	Unsigned	0x00	0xFFF	+X PANEL V
-X PANEL V	1	Unsigned	0x00	0xFFF	-X PANEL V
+Y PANEL V	2	Unsigned	0x00	0xFFF	+Y PANEL V
-Y PANEL V	3	Unsigned	0x00	0xFFF	-Y PANEL V
+Z PANEL V	4	Unsigned	0x00	0xFFF	+Z PANEL V
-Z PANEL V	5	Unsigned	0x00	0xFFF	-Z PANEL V
Not used	6	-	-	-	-
Not used	7	-	-	-	-

3.1.2 The measured data fields for Device 2 and their associated ADS 7828 channels shall be as shown in Table 2.

Table 2

Field	Channel	Type	Min Value	Max Value	Description
PSU PCB Temperature	0	Unsigned	0x00	0xFFF	Temperature of PSU card
+X PANEL T	1	Unsigned	0x00	0xFFF	+X PANEL T
-X PANEL T	2	Unsigned	0x00	0xFFF	-X PANEL T
+Y PANEL T	3	Unsigned	0x00	0xFFF	+Y PANEL T
-Y PANEL T	4	Unsigned	0x00	0xFFF	-Y PANEL T
+Z PANEL T	5	Unsigned	0x00	0xFFF	+Z PANEL T
-Z PANEL T	6	Unsigned	0x00	0xFFF	-Z PANEL T
PSU Current	7	Unsigned	0x00	0xFFF	PSU Output Current

3.1.3 Measurements shall be made in relation to the v_regulated voltage on the IHU.

3.1.4 For each Device the IHU shall poll each channel in channel number order.

Date: May 21, 2014
Version: Version 1.09

AMSAT Fox-1A

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Vulcan Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
March 3, 2013	1.00	Initial version
March 7, 2013	1.01	Correct use of I ² C (1.2) and EXP1 (2.3.3)
March 31, 2013	1.02	Command Message CRC8 to include address byte, change to commands, modified figure 3, deleted figure 4
March 31, 2013	1.03	Delete TYPE from message tables, add SET TIME response return values
March 31, 2013	1.04	Add CMD_VERSION_ERR to Error Code table
April 2, 2013	1.05	Correct 6.5 Figure 3, remove 0x0005, 0x0201, 0x0210, 0x0281, 0x0300, and 0x0301 commands
September 17, 2013	1.06	Change type format to exclude code type, add Min/Max Values
October 7, 2013	1.07	Revised Table 1 and 3.2.1 added 3.5.1.1 for clarification on Experiment Enable 1 states
November 7, 2013	1.08	Added 3.1.2 and 3.1.3 regarding minimum power levels for experiment operation
May 21, 2014	1.09	Revised 3.1.2 and 3.1.3 to read <= 3.3V

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I²C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Vanderbilt University Vulcan Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

- 2.1.1 The IHU shall initiate a command to the EXP1.
- 2.1.2 The EXP1 shall send a reply to each IHU request.
- 2.1.3 Message bit order shall be Big Endian.
- 2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.
- 2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.
- 2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

- 2.2.1 Each message shall contain a header block.
- 2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.
 - 2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

- 2.3.1 The I²C Vdd shall be 3.0V.
- 2.3.2 The bus speed shall be Fast (400kbit/s).
- 2.3.3 The EXP1 I²C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 The IHU shall not power on the experiment if the power bus voltage (VBATT) is less than or equal to 3.3 Volts.

3.1.3 The IHU shall perform the Experiment Cease Operation Sequence and the Experiment Power Off Sequence if the power bus voltage (VBATT) falls to less than or equal to 3.3 Volts while the experiment is powered on.

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set the Experiment Enable 1 pin LOW.

3.5.1.1 The absence of a HIGH state on the Experiment Enable 1 pin shall be construed as a LOW state whether the pin is actually LOW, or in a high-impedance state.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command Name	Size (Bytes)	Type	Min Value	Max Value	Description
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I ² C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	Size (Bytes)	Type	Min Value	Max Value	Description
STANDBY	2	Unsigned	0x0001	0x0001	Enter Standby State
ACTIVE	2	Unsigned	0x0003	0x0003	Activate Experiments
HALT	2	Unsigned	0x0004	0x0004	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
BYTES TO SEND	2	Unsigned	0x00	0xFFFF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0x0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – NOT USED
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – NOT USED
COMPLETED RUN STATE	4	1 = Completed the run state – NOT USED
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

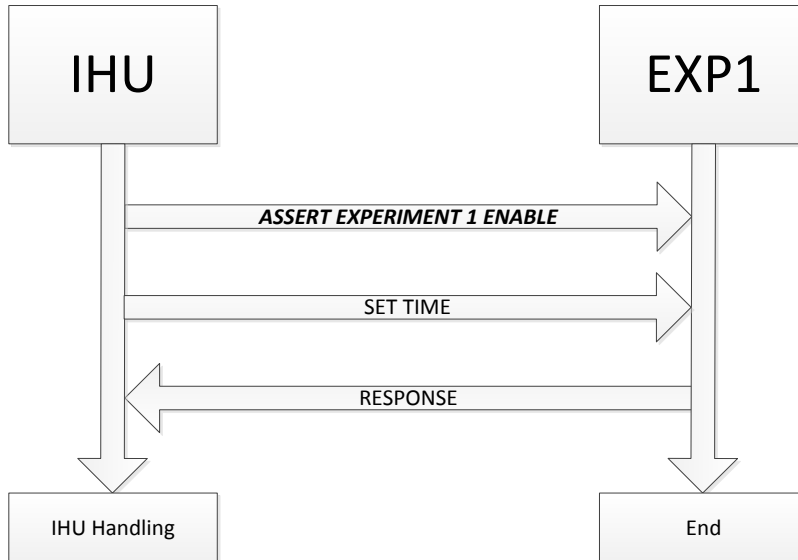
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

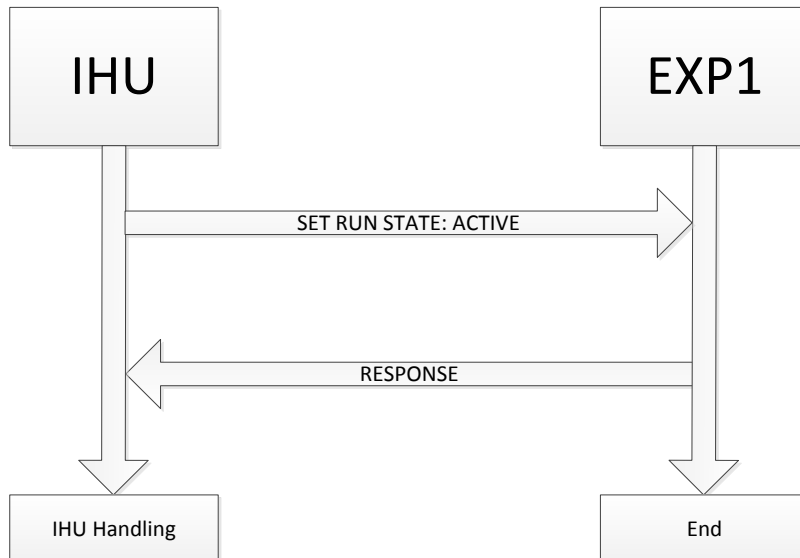
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

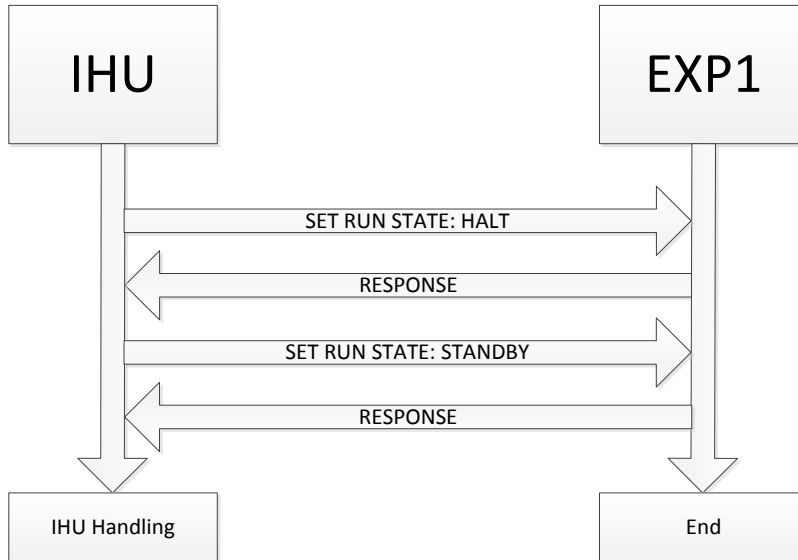
6.1 EXPERIMENT POWER ON SEQUENCE



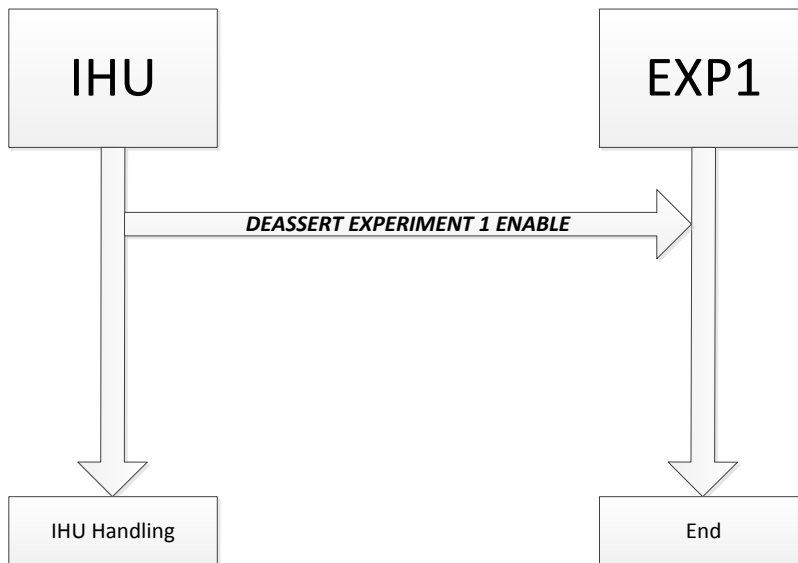
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

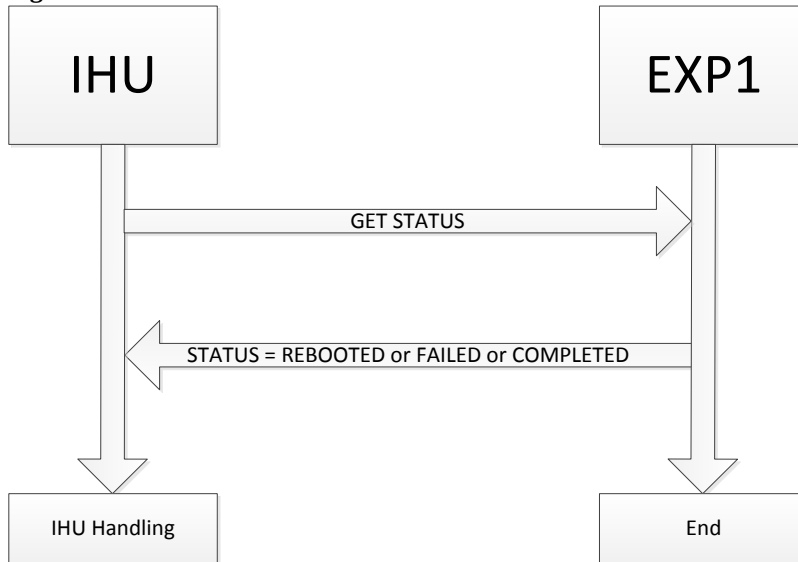


Figure 2

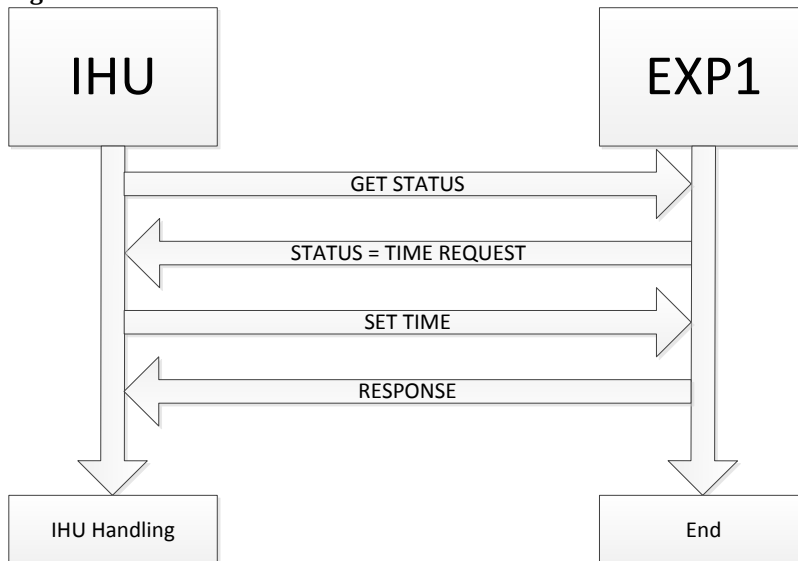
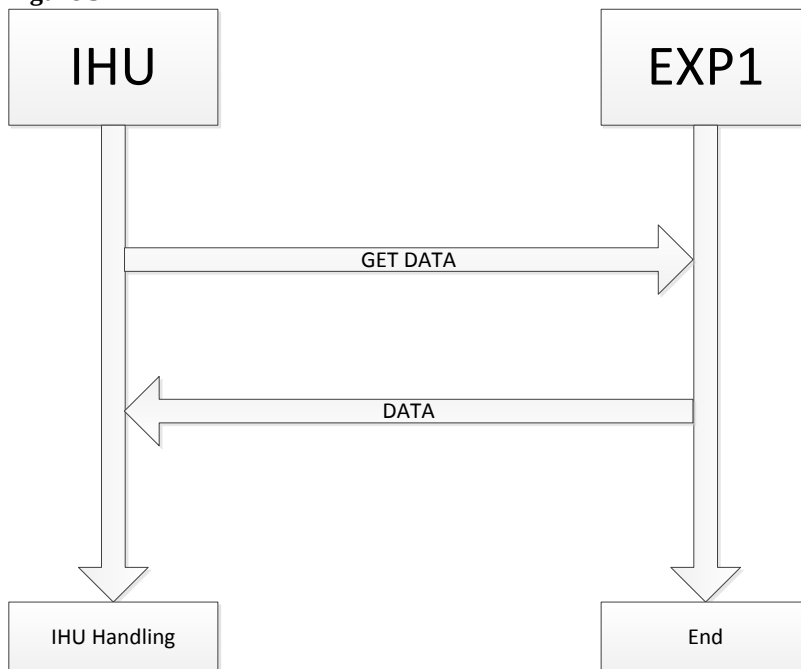


Figure 3



Date: June 26, 2014
Version: Version 1.20

AMSAT Fox-1A

IHU to Experiment 4 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 3 of the satellite, known as the VT Camera Experiment and abbreviated herein as EXP3.

1.1 Document History

DATE	VERSION	SUMMARY
January 24, 2013	1.00	Initial version
February 20, 2013	1.01	Specify byte order as little endian
May 21, 2013	1.10	Update data TYPE names
October 4, 2013	1.11	Change type format to exclude code type, add Min/Max Values, add thermistor circuit
October 7, 2013	1.12	Modify Table 1 to clarify Experiment Enable 4 pin states
June 26, 2014	1.20	Add "No Earth Image Available" to NN description in Table 6, remove section 7 thermistor requirement no longer applicable, change all references to EXP4 to read EXP3 reflecting proper location of experiment

1.2 Document Scope

This document will specify the control of EXP3, the messaging format, and the serial bus hardware operation for the communications between the IHU and the EXP3.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

- 2.1.1 The IHU shall initiate a command to the EXP3.
- 2.1.2 The EXP3 shall send a reply to each IHU request.
- 2.1.3 Message bit order shall be Little Endian.
- 2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP3.
- 2.1.5 The EXP3 shall take no action in the event of an invalid or improper message from the IHU.
- 2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

- 2.2.1 Each message shall contain a header block.
- 2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

- 2.3.1 The bus levels shall be 3.0V.
- 2.3.2 The bus data speed shall be 38400 bit/s.
- 2.3.3 The serial bus communication shall be asynchronous.
- 2.3.4 The number of data bits shall be 8.
- 2.3.5 The number of stop bits shall be 1.
- 2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP3 by the Experiment Enable 4 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 Upon signaling Power On to the EXP3, the IHU shall not send any message to the EXP3 for a minimum of 100 milliseconds.

3.2 Experiment Operation Sequence

3.2.1 Upon Power On the IHU shall determine the state of the EXP3 by sending an Is Camera Ready command message.

3.2.2 The IHU shall not send a Transmit Data Block command message prior to receiving a Camera Ready reply message from the EXP3.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command, Reply, and Data block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP3 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	RR TT	RR TT	Command

4.2.2 The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command	Description
RR	Is Camera Ready?
TT	Transmit Data Block

4.3 Reply Message Block

4.3.1 The reply message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
REPLY	2	Alpha	NN YY FF	NN YY FF	Reply

4.3.2 The reply message block shall contain one reply in the REPLY field as shown in table 6.

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IHU to Experiment 4 ICD



Table 6

Command	Description
NN	Camera Not Ready or No Earth Image Available
YY	Camera Ready
FF	Camera Failed

4.4 Message Data Block

4.4.1 The message data block shall be constructed as shown in Table 7.

Table 7

Field	Size (Bytes)	Type	Min Value	Max Value	Description
DESCRIPTOR	2	Unsigned	-	-	Line ID and Payload Length
PAYLOAD	Variable	Unsigned	-	-	Array of (Payload Length) bytes
CHKSUM	2	Unsigned	-	-	16 bit accumulator sum of bytes in HEADER and PAYLOAD

4.4.2 The bits of the message data block DESCRIPTOR bytes shall be constructed as shown in Table 8.

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description
Line ID	6	Unsigned	0x01	0x3C	640 x 8 pixel picture line number (1 is top, 60 is bottom)
Payload Length	10	Unsigned	0x01	0x3FF	Total number of bytes in PAYLOAD

4.4.2.1 The Line ID shall compose the 6 MSB and the Payload Length shall compose the 10 LSB.

5 Message Integrity

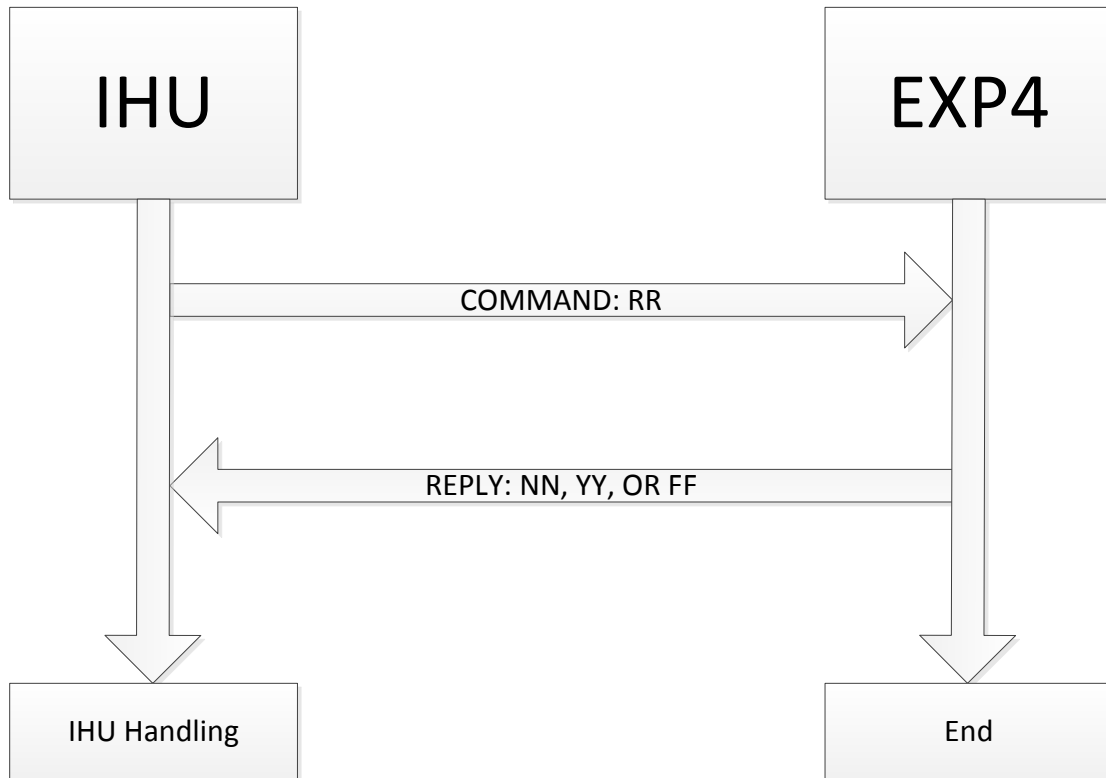
5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails, the message shall be considered invalid.

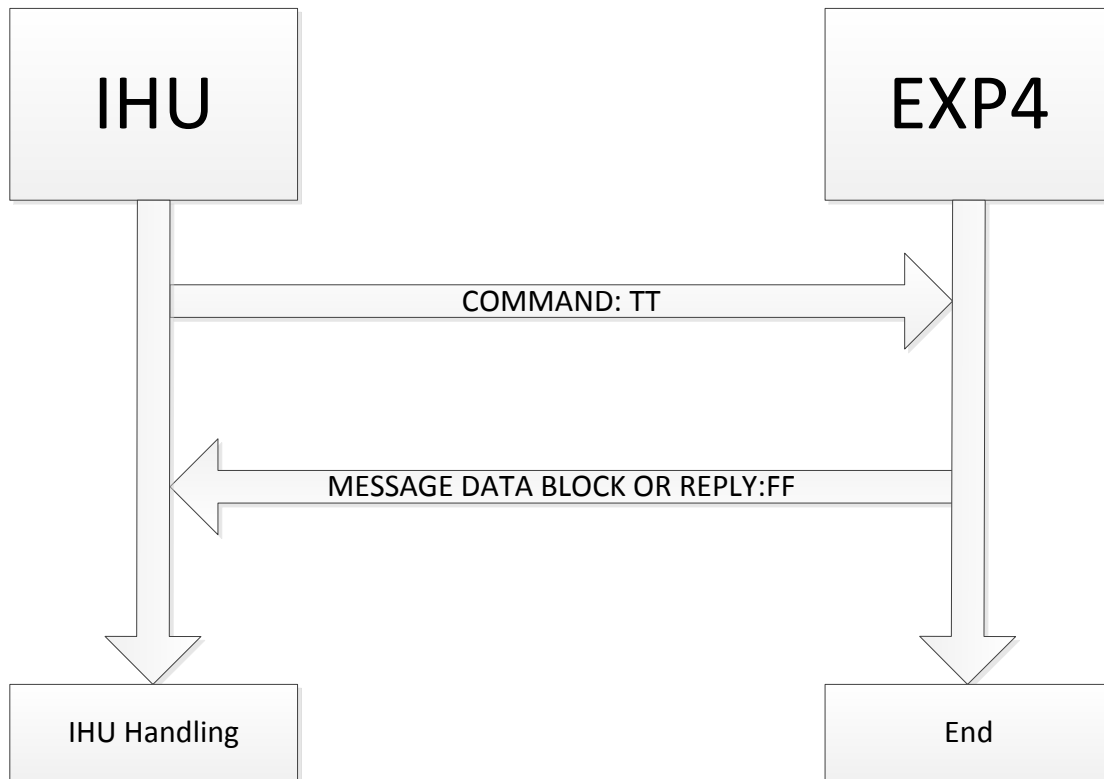
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

6.1 RR COMMAND



6.2 TT COMMAND



Date: September 30, 2014

Version: Version 2.00

AMSAT *Fox-1A*

Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1A telemetry and experiment telemetry. This specification includes the both slow and high speed formats.

Document History

DATE	VERSION	SUMMARY
April 25, 2013	1.01	Remove TX PA Temperature and TX Osc Temperature, add TX Temperature
May 21, 2013	1.2	High speed downlink details added
May 27, 2013	1.3	Remove Radiation Experiment Telemetry Frame, resize Radiation Experiment Data Frame, renumber Payload Types, added Slow Speed Link Layer Transmission Scheduling, changed Reset Count to 16 bits
June 6, 2013	1.31	Reduce BATT CPU, PSU CPU, IHU CPU, TX Temp, RX Osc Temp from 12 to 8 bit value, add IHU Error Data field to Telemetry Minimum Values Frame
June 26, 2013	1.32	Correct Payload Type numbers in Table 6
August 13, 2013	1.40	Changes due to new BATT telemetry values, delete Type 4 from idle telemetry
August 26, 2013	1.41	Change Receiver Osc Temperature to Receiver Card Temperature, remove TOTAL MPPT I, update 2.2.9.1 and 2.2.9.1.1 to reflect variable size of Radiation Experiment Data available
September 14, 2013	1.42	Added 3.1.2, Payload type 0 debug frame, made Scan Line Segment – Picture Count size 8 bits, add RSSI to Payloads 1, 2, and 3, change type format to exclude code type, add Min/Max Values
September 16, 2013	1.43	Added EXP4 temperature to Payloads 1, 2, and 3, changed PSU CPU temp to PSU card temp

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DATE	VERSION	SUMMARY
October 15, 2013	1.44	Correct bit count for frame Type 3, change calculated spin rate to remove PSU reference
November 18, 2013	1.45	Expanded all temperature fields to 12 bits, redo 3.1 payload order, add 2.2.7.3 and 2.2.7.4, update SPIN to show bit pattern, add System I ² C Failure indications, add Ground Command TLM reset count, add IHU Soft Error Data, add IHU Hard Error Data, increase IHU Error Data to 32 bits, clarify which fields are raw values, added 2.2.7 5 padding slow speed frames, 2.2.8 for slow speed trailer info
January 13, 2014	1.50	Redo 3.2 beacon payloads
January 13, 2014	1.51	Change 3.2.1 to allow payload type 2 and 3 only with the voice ID
January 13, 2014	1.52	Correct 2.2.9 high speed link layer header structure to show 16 bits on the Reset Count
January 14, 2014	1.53	Correct Table 4 and Table 5 Reset Count Max Value to 0xFFFF to match use of 16 bits
February 10, 2014	1.54	Modify Table 11 to read "Experiment 1 Data" in the description, added Safe Mode Indication bit to payload 2 and 3, changed Filler bit size to 1 in payload 2 and 3.
March 19, 2014	1.55	Move IHU Soft Error Data to Payload Type 3, Move IHU Error Data to Payload Type 1 and rename to IHU Diagnostic Data, update Table 1 Bit Rate to 200 bps and Spectral Efficiency to 2 bps/Hz, remove Scrambler reference from Table 1 and Table 2.
March 24, 2014	1.56	Add timestamp elements to Payload 2 and Payload 3 for specific MAX or MIN last changed
April 23, 2014	1.57	Fix 4.4 BATT Board Temperature description to read Low instead of High
June 10, 2014	1.58	Remove Payload Type 2 MRAM Error Count, Add PSU DC current, PSU DC high current, PSU DC low current to Payload Type 1, 2, 3 respectively
September 30, 2014	2.00	Reorder fields in Payload Type 1, 2, 3, delete filler fields, add filler bits to Table 5

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1A spacecraft.

1.2 References

1. Fox1 IHU to RF ICD
2. Fox1 IHU to Battery ICD
3. Fox1 IHU to PSU ICD
4. Fox1 IHU to Attitude Determination Experiment ICD
5. Fox1 IHU Software Architecture Specification
6. Fox1 IHU to Experiment 1 ICD
7. Fox1 IHU to Experiment 4 ICD

1.3 Definitions

- 1.3.1 Slow Speed Downlink – Data transmitted at approximately 100 bits per second in the audio portion below 300 Hz simultaneous with the transponder audio.
- 1.3.2 High Speed Downlink – Data transmitted at approximately 9600 bits per second using the entire downlink audio passband.
- 1.3.3 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.
- 1.3.4 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.
- 1.3.5 Frame – A defined set of data with a specific overall size comprised of fields of a specific bit or byte length.

2 Protocol Structure

2.1 Physical Layer

2.1.1 The physical layer includes options for slow-speed and high speed operation.

2.1.2 Slow speed operation uses frequency-shift keying and is transmitted in the sub-audible part of the audio downlink below 300 Hz. It may be transmitted simultaneously with voice or other audio signals. The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	200 bps
Spectral efficiency	2 bps/Hz
Modulation type	Non-coherent Frequency Shift Keying (FSK)
Signal bandwidth	10 Hz to 200 Hz (-3 dB points)
FSK Deviation	500 Hz
Spectral Mask	-20 dB at 300 Hz
RF Channel Bandwidth	1200 Hz

2.1.3 High speed operation uses frequency-shift keying and is transmitted using the entire RF downlink bandwidth. The details of the physical layer are shown in Table 2. *Note that this is the same as the G3RUH modem.*

Table 2

Bit Rate	9600 bps
Spectral efficiency	2 bps/Hz
Modulation type	non-coherent frequency shift keying (FSK)
Signal bandwidth	10 Hz to 4800 Hz (-3 dB points)
FSK Deviation	3 kHz
Spectral Mask	-60 dB at 7500 Hz
RF Channel Bandwidth	20 kHz

2.2 Link Layer

2.2.1 The link layer protocol provides multiplexing, packet identification and forward error correction.

2.2.2 The link layer shall include a header and a trailer surrounding the applications layer payload to form data packets as shown in Table 3.

Table 3

Header	Applications Payload	Trailer
--------	----------------------	---------

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, high speed data, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight.

2.2.5 Bits shall be transmitted in the order of most significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The Slow Speed link layer header structure shall be as shown in Table 4.

Table 4

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFFF	This is the IHU uptime in seconds since the last reset
Type	4	Unsigned	0x00	0x0F	This identifies the payload type

2.2.7.1 Payload type shall be as specified in the application layer payload data.

2.2.7.2 Each Slow Speed link layer structure shall contain only one payload type.

2.2.7.3 Reset Count and Uptime shall reflect the time at which the payload data was collected.

2.2.7.4 Reset Count and Uptime shall not be changed if the payload data has not been updated.

2.2.7.5 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 58 bytes length for each.

2.2.8 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.)

2.2.9 The High Speed link layer header structure is shown in Table 5.

Table 5

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFFF	This is the IHU uptime in seconds since the last reset
(No Value)	4	Unsigned	0x00	0x00	4 bit filler

2.2.10 The High Speed link layer applications payload shall contain data from all payload types, as shown in table 6.

Table 6

Payload Type	Size (Bytes)	Description
1	60	Real-Time Telemetry Frame
2	60	Telemetry Maximum Values Frame
3	60	Telemetry Minimum Values Frame
5	Variable 1 - 4300	Camera JPEG Data Frame
4	58	Radiation Experiment High Speed Data Frame

2.2.10.1 A varying number of Radiation Experiment Data bytes shall be sent to fill the applications payload size to a total of 4600 bytes if the payload type 5 data is less than 4300 bytes.

2.2.10.1.1 When less than a sufficient number of bytes to contain a useful data frame remain to fill to 4600 bytes, the remaining bytes shall be filled with zeros.

2.2.10.2 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 60 bytes length for each.

2.2.11 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.) Twenty one code words will be populated in parallel, with 1 byte being added to each code word in sequence until all

bytes have been processed. The last code word will be partially filled and should be virtually padded with 77 bytes. The data will then be sent sequentially with 8b10b coding. Twenty one sets of 32 parity bytes will follow after all data has been sent for the high speed frame.

3 Slow Speed Link Layer Transmission Scheduling

3.1 While IHU PTT is asserted Payload Types contained in the Link Layer Applications Payload shall rotate, changing type with each successive link layer transmitted, in the following order:

- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 2
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 3
- Type 4

3.1.1 The above order shall be repeated so long as IHU PTT is asserted.

3.1.2 Each time IHU PTT is asserted the order shall begin at the top.

3.1.3 The IHU PTT shall not be de-asserted during transmission of a Link Layer.

3.2 While beacon message is sent during idle timer expired the Payload Types contained in the Link Layer Applications Payload shall be transmitted in alternating sets, one set per beacon message:

Set 1:

- Type 1
- Type 2

Set 2:

- Type 1
- Type 3

3.2.1 The payload type 2 or 3 data shall be sent simultaneously with the voice ID.

4 Application Layer Payload Data

4.1 Payload Type 0 – Debug Frame (NOT TO BE TRANSMITTED FOR FLIGHT)

Table 7

Field	Size (Bits)	Type	Min Value	Max Value	Description
UNDEFINED	1 - 464	Undefined	-	-	Debug data for ground testing

4.2 Payload Type 1 - Real-Time Telemetry Frame (Size = 429 bits)

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFFF	Battery pair A voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFFF	Battery pairs A+B voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFFF	Battery pair A temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFFF	Battery pair B temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFFF	Battery pair C temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFFF	Total Battery DC current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFFF	PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFFF	+X solar panel voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFFF	-X solar panel voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFFF	+Y solar panel voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFFF	-Y solar panel voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFFF	+Z solar panel voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFFF	-Z solar panel voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFFF	+X solar panel temperature raw value	168
-X PANEL T	12	Unsigned	0x00	0xFFFF	-X solar panel temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFFF	+Y solar panel temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFFF	-Y solar panel temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFFF	+Z solar panel temperature raw value	216

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Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-Z PANEL T	12	Unsigned	0x00	0xFFFF	-Z solar panel temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFFF	PSU card temperature raw value	240
SPIN	12	Signed	0x00	0xFFFF	Calculated spin rate RPM using solar cells Bit 11 = sign Bits 10 to 8 = integer Bits 7 to 0 = fraction	252
TX PA Current	12	Unsigned	0x00	0xFFFF	Transmit power amplifier current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFFF	Transmitter card temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFFF	Receiver card temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFFF	Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFFF	CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Raw Angle	348
EXP 4 Temperature	12	Unsigned	0x00	0xFFFF	Experiment 4 card temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFFF	PSU DC current	372
IHU Diagnostic Data	32	Unsigned	-	-	Diagnostic Data on IHU Performance	384
Experiment Failure Indication	4	Unsigned	0x00 0x08	0x01 0x09	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed	416

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Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
System I2C Failure Indications	3	Unsigned	0x00	0x07	Bit 0 is BATT Bit 1 is PSU Device 1 Bit 2 is PSU Device 2 State: 0 = Working, 1 = Failed	420
Number of Ground Commanded TLM Resets	4	Unsigned	0x00	0x0F	Number of times command stations reset stored telemetry	423
Antenna Deploy Sensors	2	Unsigned	0x00	0x03	Bit 0 is RCV Bit 1 is XMT State: 0 = stowed 1 = deployed	427

4.3 Payload Type 2 - Telemetry Maximum Values Frame (Size = 458 bits)

Table 9

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFFF	Battery pair A high voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFFF	Battery pairs A+B high voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFFF	Battery pairs A+B+C high voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFFF	Battery pair A high temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFFF	Battery pair B high temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFFF	Battery pair C high temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFFF	Battery DC high current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFFF	High PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFFF	+X solar panel high voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFFF	-X solar panel high voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFFF	+Y solar panel high voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFFF	-Y solar panel high voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFFF	+Z solar panel high voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFFF	-Z solar panel high voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFFF	+X solar panel high temperature raw value	168

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Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFFF	-X solar panel high temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFFF	+Y solar panel high temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFFF	-Y solar panel high temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFFF	+Z solar panel high temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFFF	-Z solar panel high temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFFF	PSU card high temperature raw value	240
SPIN	12	Signed	0x00	0xFFFF	Highest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFFF	Transmit power amplifier high current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFFF	Transmitter card high temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFFF	Receiver card high temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFFF	High Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFFF	High CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Highest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Highest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Highest Raw Angle	348

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Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFFF	Experiment 4 card high temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFFF	PSU DC high current	372
IHU Hard Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Hard Errors	384
MAX Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MAX, total number of times IHU has reset since initial on-orbit startup	416
MAX Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFFF	At last MAX, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457

4.4 Payload Type 3 - Telemetry Minimum Values Frame (Size = 458 bits)

Table 10

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFFF	Battery pair A low voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFFF	Battery pair A+B low voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFFF	Battery pair A+B+C low voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFFF	Battery pair A low temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFFF	Battery pair B low temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFFF	Battery pair C low temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFFF	Battery DC low current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFFF	Low PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFFF	+X solar panel low voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFFF	-X solar panel low voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFFF	+Y solar panel low voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFFF	-Y solar panel low voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFFF	+Z solar panel low voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFFF	-Z solar panel low voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFFF	+X solar panel low temperature raw value	168

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Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFFF	-X solar panel low temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFFF	+Y solar panel low temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFFF	-Y solar panel low temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFFF	+Z solar panel low temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFFF	-Z solar panel low temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFFF	PSU card low temperature raw value	240
SPIN	12	Signed	0x00	0xFFFF	Lowest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFFF	Transmit power amplifier low current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFFF	Transmitter card low temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFFF	Receiver card low temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFFF	Low Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFFF	Low CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Lowest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Lowest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFFF	Lowest Raw Angle	348

AMSAT Fox-1A
Downlink Specification



Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFFF	Experiment 4 card low temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFFF	PSU DC low current	372
IHU Soft Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Soft Errors	384
MIN Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MIN, total number of times IHU has reset since initial on-orbit startup	416
MIN Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFFF	At last MIN, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457

4.5 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 11

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Data	58	Unsigned	-	-	Experiment 1 Data

4.6 Payload Type 5 - Camera JPEG Data Frame (Size is variable)

Table 12

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Picture Lines	8	Unsigned	-	-	Picture Data ¹

¹ See section 5 for Picture Data Structure

5 Picture Data Structure

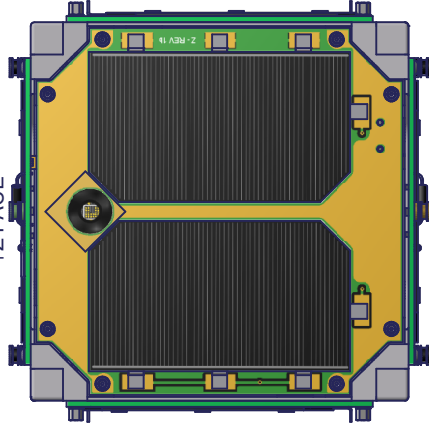
5.1 Scan Line Segment

Table 13

Field	Size (Bits)	Type	Min Value	Max Value	Description
Picture Counter	8	Unsigned	0x00	0xFF	Picture count indicator
Scan Line Number	6	Unsigned	0x00	0x3B	0x00 = top scan line
Scan Line Length	10	Unsigned	0x001	0x3FF	Count of bytes in the scan line
Scan Line Data	Variable	Unsigned	-	-	(Fragment Length) Scan Line Data
End of JPEG Data	8	Unsigned	0xAA	0xAA	Indicates end of Picture Data for use in Applications Payload construction

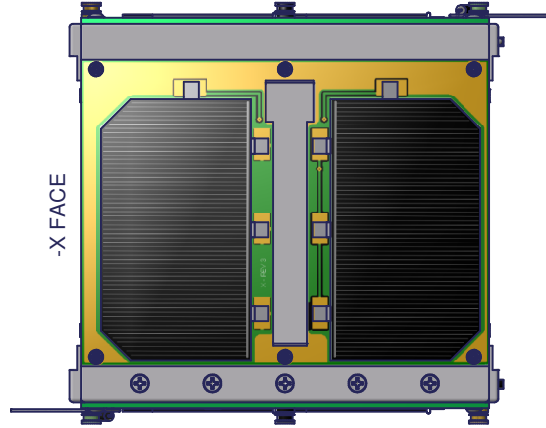
5.1.1 Total Scan Line Segment data size for one Applications Payload frame including end of JPEG data indicator byte shall not exceed 4300 bytes.

+Z FACE

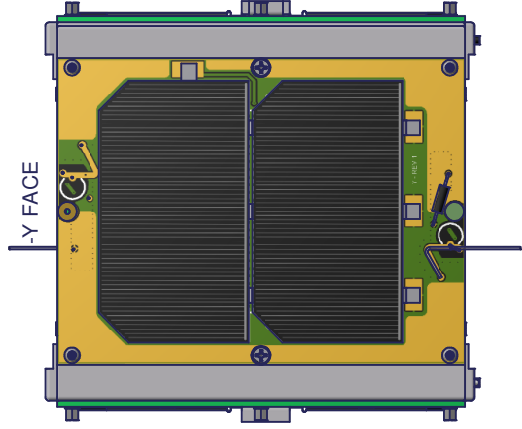


DEPLOYED
(ANTENNAS CROPPED)
SCALE 1 : 2

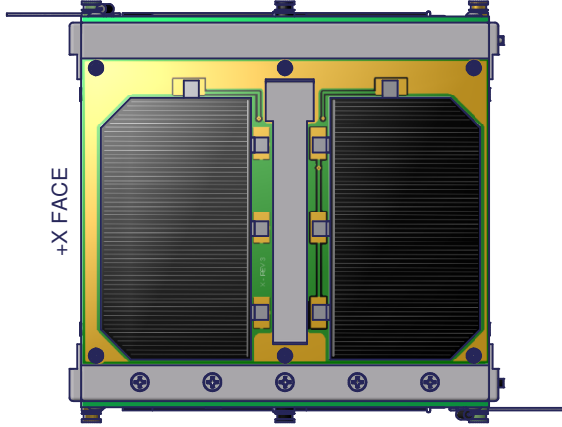
-X FACE



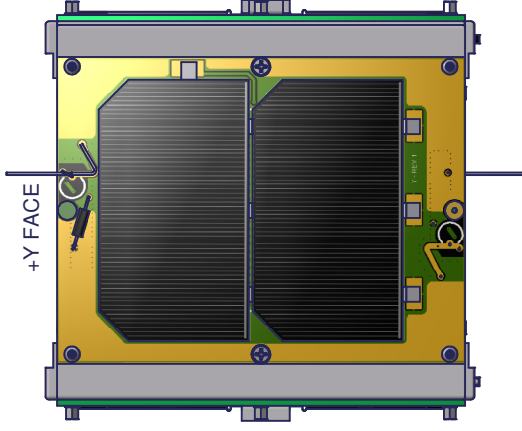
-Y FACE



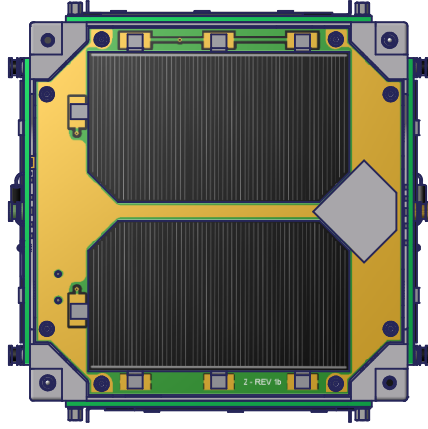
+X FACE



+Y FACE

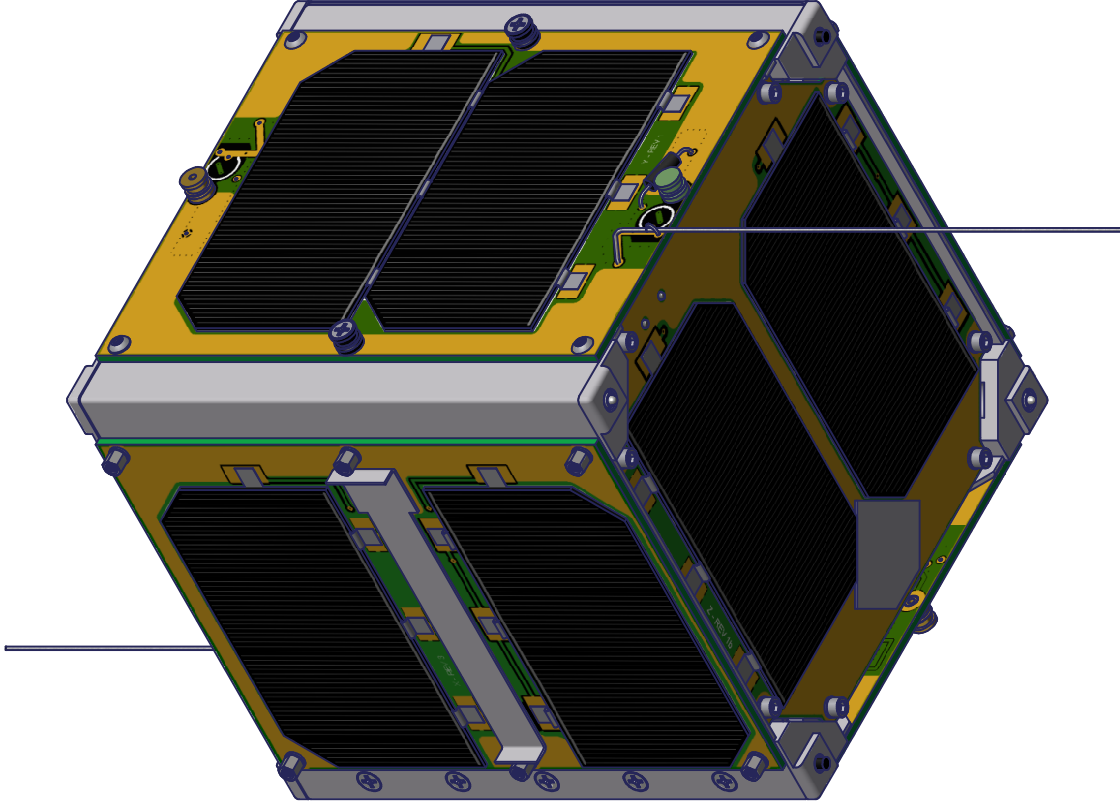


-Z FACE

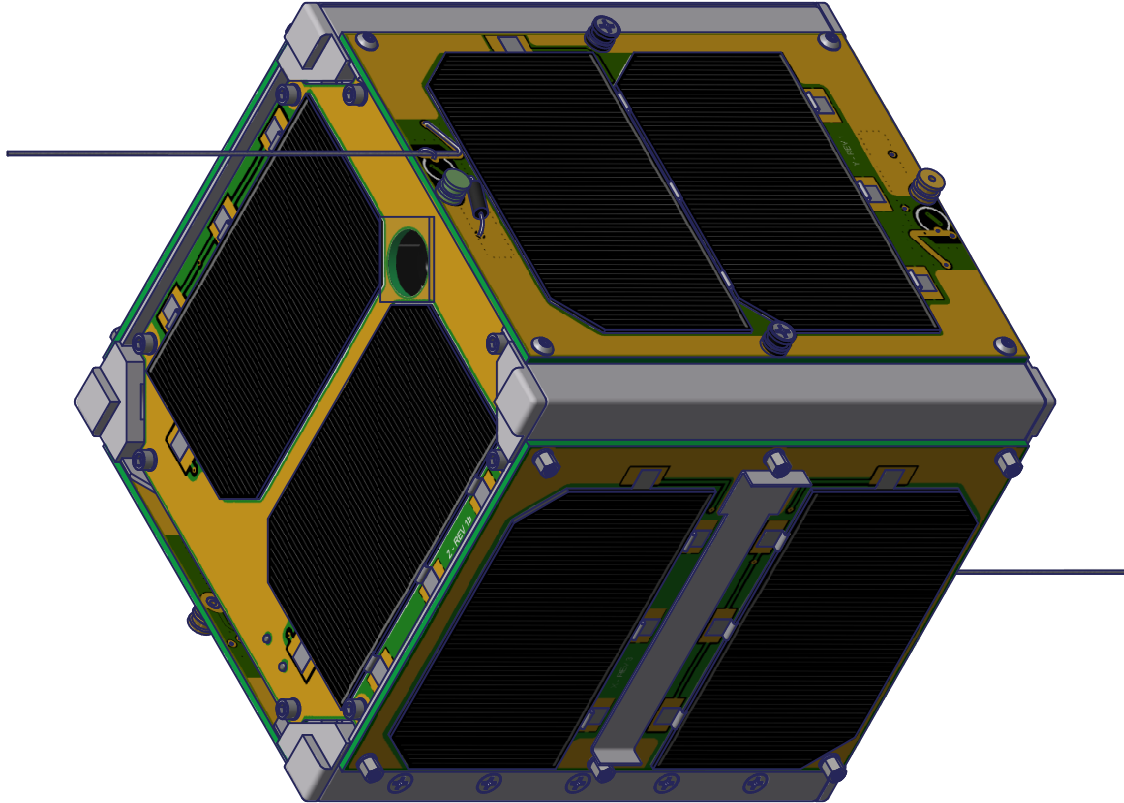


FOX1 ASSEMBLY				
SIZE	DATE	DWG NO.	REV.	REV.
A	2014-7-16	FOX-ME-103	0.5	0.5
SCALE	1 : 2	UNLESS NOTED OTHERWISE: mm (in) TOL XX ± 0.2 XX ± 0.1		
SHEET				1 OF 5

ISO -X-Y-Z
SCALE 3 : 4



ISO +X+Y+Z
SCALE 3 : 4

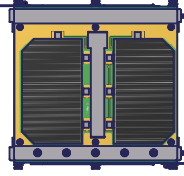


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FOX1 ASSEMBLY

SIZE	DATE	DWG NO.	REV.
A	2014-7-16	FOX-ME-103	0.5
SCALE	3 : 4	UNLESS NOTED OTHERWISE: mm [in] TOL XX ± 0.2 XX ± 0.1	SHEET 2 OF 5

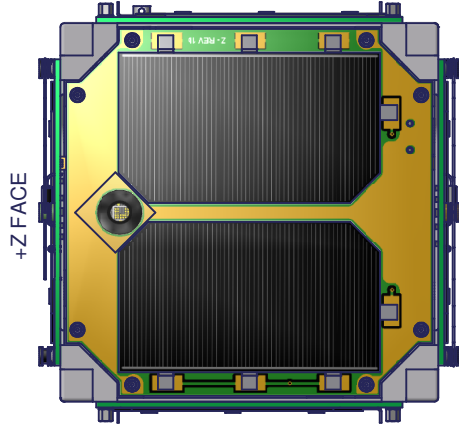
+X FACE
TRUE ANTENNA LENGTHS
SCALE 0.2:1



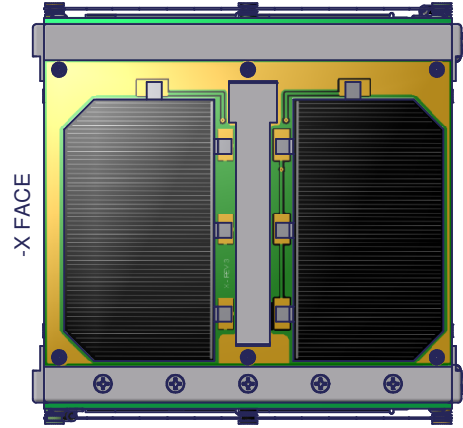
AMSAT FOX

FOX1 ASSEMBLY

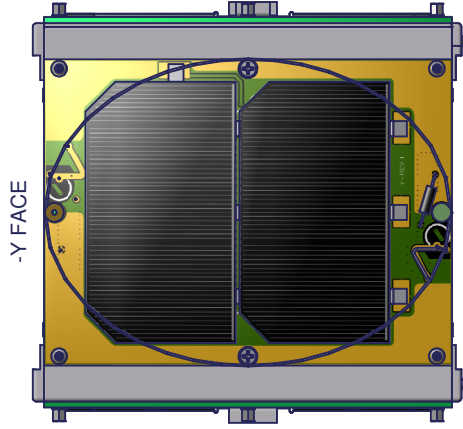
SIZE	DATE	DWG NO.	REV.
A	2014-7-16	FOX-ME-103	0.5
SCALE	1 : 5	UNLESS NOTED OTHERWISE: (mm) (in) TOL XX ± 0.2 XX ± 0.1	
			SHEET 3 OF 5



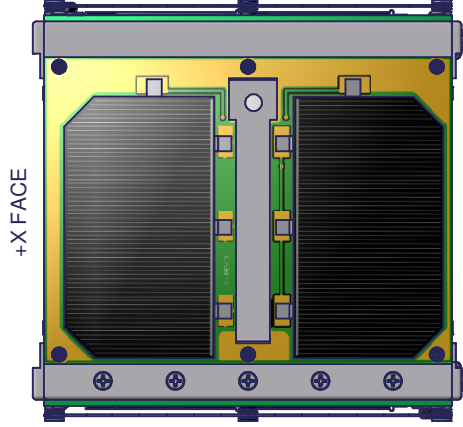
+Z FACE



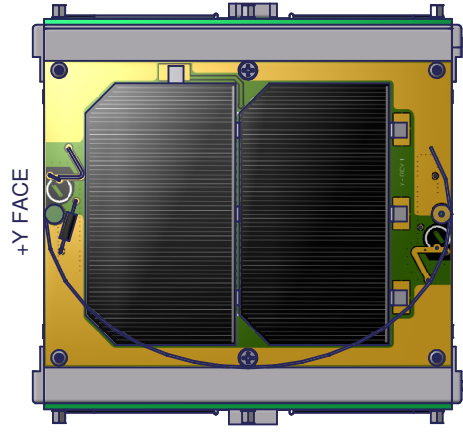
-X FACE



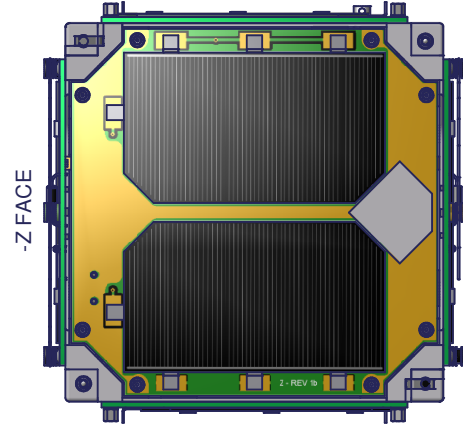
-Y FACE



+X FACE



+Y FACE



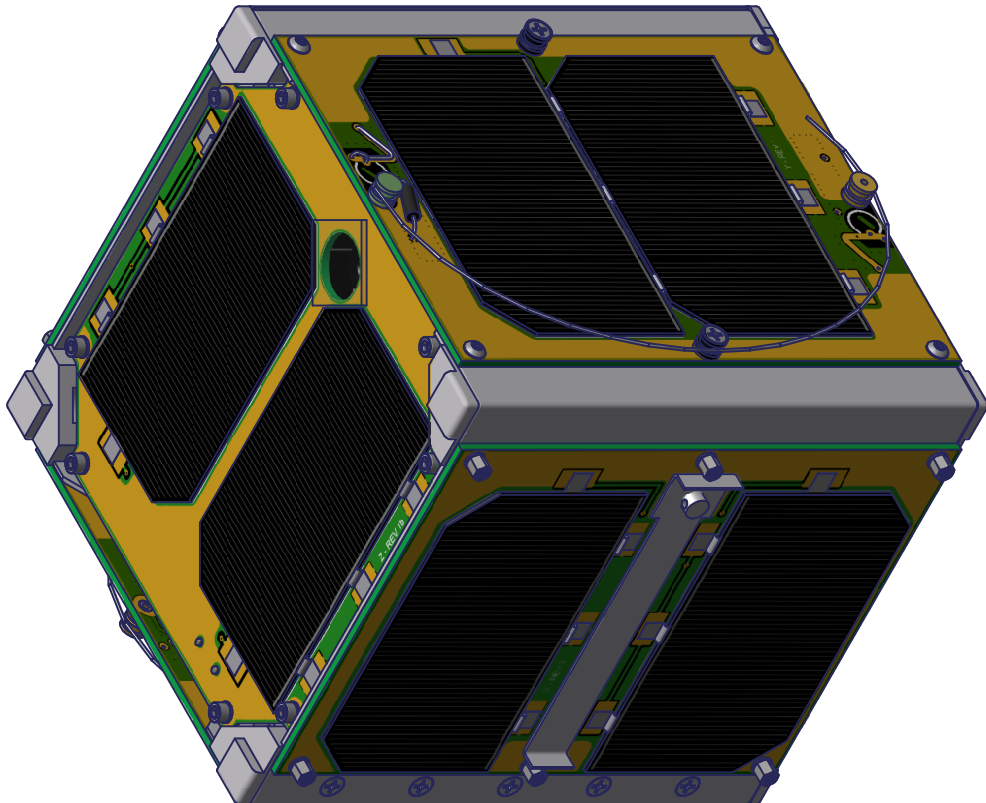
-Z FACE

STOWED
SCALE 1 : 2

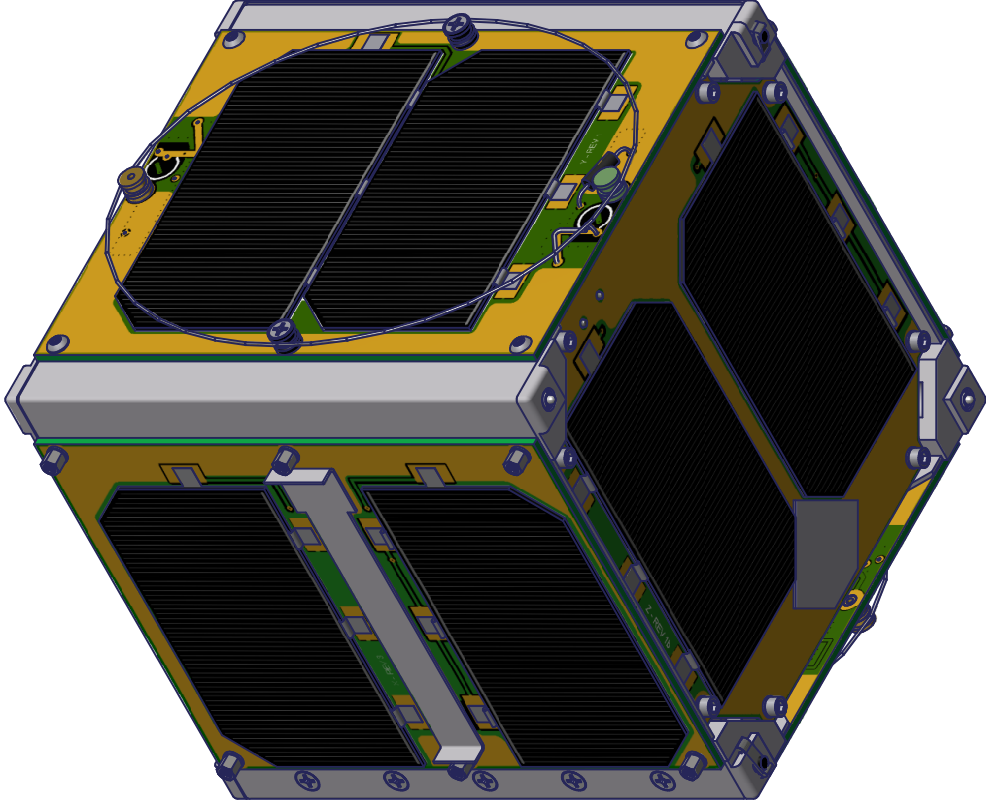
AMSAT FOX

FOX1 ASSEMBLY				
SIZE	DATE	DWG NO.	REV.	
A	2014-7-16	FOX-ME-103	0.5	
SCALE	1 : 2	UNLESS NOTED OTHERWISE: mm [in] TOL XX ± 0.2 XX ± 0.1		SHEET 4 OF 5

ISO +X+Y+Z
SCALE 3 : 4



ISO -X-Y-Z
SCALE 3 : 4



AMSAT FOX

FOX1 ASSEMBLY				
SIZE	DATE	DWG NO.	REV.	
A	2014-7-16	FOX-ME-103	0.5	
SCALE	UNLESS NOTED OTHERWISE: mm [in]: TOL XX ± 0.2 XX ± 0.1			
3 : 4	SHEET 5 OF 5			

Section G:

Payload Specification for 3U, 6U, 12U and 27U Canisterized Satellite Dispenser

The following material is provided by Planetary Systems Corporation, an invited guest at the 2014 AMSAT Space Symposium. Ryan Hevner will demonstrate the operation of his company's 6U Canisterized Satellite Dispenser at the Symposium.

This material is included because it provides an excellent example of the complex engineering that is required to place a secondary payload on a launch vehicle. It has not been reviewed or approved by AMSAT, and all questions should be directed to Planetary Systems Corporation.

For more information please visit the company's web site:

<http://www.planetarysystemscorp.com/>

This is a standalone specification intended for payload designers. Planetary Systems Corporation does not design or manufacture payloads.

FEATURES AND BENEFITS

- **Preloaded Payload Tabs** create a modelable load path to the payload so strength at critical locations like reaction wheel bearings can be accurately calculated. Preload means the payload can't jiggle and damage itself.
- **Separation Electrical Connector** allows communication and charging between payload and launch vehicle prior to and during launch. It also grounds the payload to the CSD
- **Dispenser Constrained Deployables** greatly reduce the costs and complexity of payload deployables like solar panels and antennas.
- **Largest Volume** versus existing designs accommodates larger payloads. Payloads have 15% more volume and can be 1 inch longer than standard CubeSats.
- **Unrestricted External Shape** eliminates need for four corner rails.
- **Safe/Arm Access on Front** ensures payload access at all times via CSD door.
- **Flight Validated** in 2013.
- **Fully Documented** mechanical and electrical interfaces and CAD models available on request allowing rapid and low cost design.
- **Parametric Design** commonality allows users easy understanding of electro-mechanical interface for 3U, 6U, 12U and 27U sizes.
- **Cross Compatible** with existing CubeSat standards via tab attachment.

DESCRIPTION

These payloads are fully contained within a Canisterized Satellite Dispenser (CSD, canister or dispenser) during launch. A CSD encapsulates the payload during launch and dispenses it on orbit. CSDs reduce risk to the primary payload and therefore maximize potential launch opportunity. They also ease restrictions on payload materials and components. This specification currently encompasses four payload sizes, 3U, 6U, 12U and 27U.

The payloads incorporate two tabs running the length of the ejection axis. The CSD will grip these tabs, providing a secure, modelable, preloaded junction. This is essential to accurately predict loads on critical components and instrumentation and prevent jiggling.

The payload may use the CSD to restrain deployables. The allowable contact zones are defined.

A payload can be built to this specification without knowledge of the specific dispenser within it will fly. Similarly, dispenser manufacturers will be ensured of compatibility with payloads that conform to this specification.

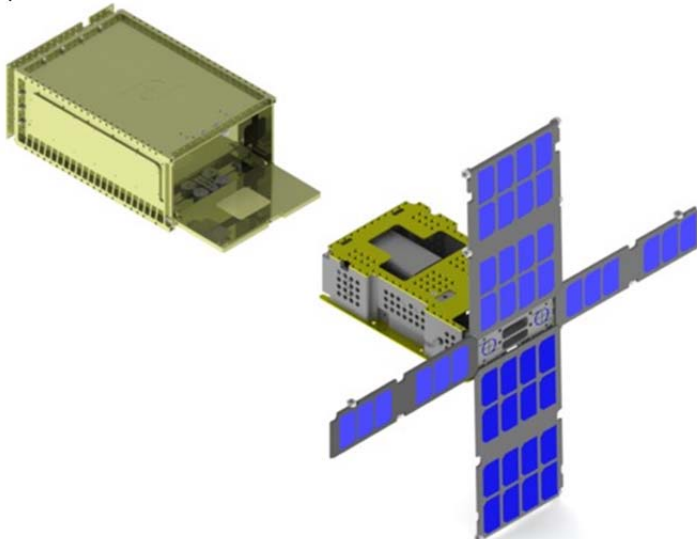


Figure 1: Payload Deploying from CSD

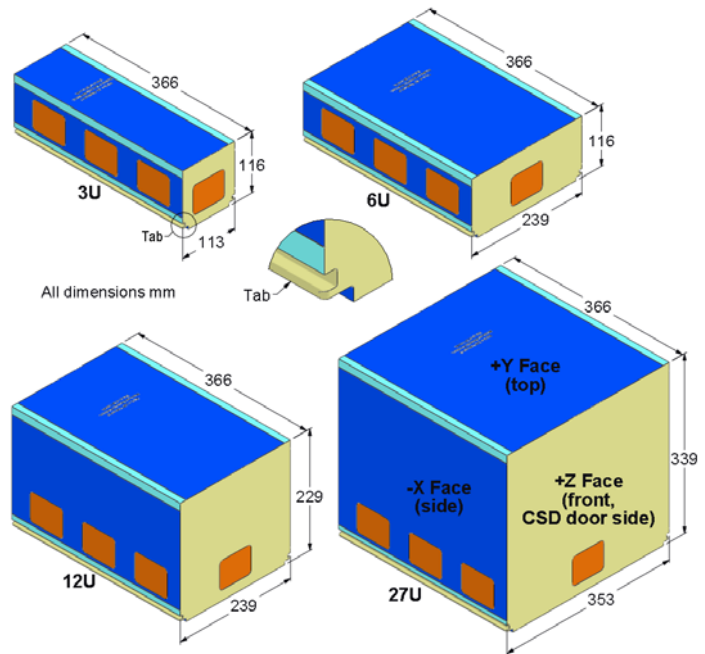


Figure 2: Payloads

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PARAMETERS

Symbol	Parameter	Conditions	Unit	3U		6U		12U		27U	
				Min	Max	Min	Max	Min	Max	Min	Max
M	Mass	At launch	kg [lb]	0	6.0 [13.2]	0	12.0 [26.4]	0	24.0 [52.9]	0	54.0 [119.0]
CM _x	Center of mass, X	Stowed in CSD	mm [in]	-20 [-0.79]	20 [0.79]	-40 [-1.57]	40 [1.57]	-40 [-1.57]	40 [1.57]	-60 [-2.36]	60 [2.36]
CM _y	Center of mass, Y	Stowed in CSD	mm [in]	10 [0.39]	70 [2.76]	10 [0.39]	70 [2.76]	55 [2.17]	125 [4.92]	100 [3.94]	180 [7.09]
CM _z	Center of mass, Z	Stowed in CSD	mm [in]	133 [5.24]	233 [9.17]	133 [5.24]	233 [9.17]	133 [5.24]	233 [9.17]	133 [5.24]	233 [9.17]
Height	Maximum payload depth, +Y dimension		mm [in]	0	109.7 [4.319]	0	109.7 [4.319]	0	222.8 [8.771]	0	332.8 [13.102]
Width	Maximum payload width from origin, ±X dimension		mm [in]	0	56.55 [2.226]	0	119.7 [4.713]	0	119.7 [4.713]	0	176.25 [6.939]
Tab Width	±X dimension		mm [in]	112.7 [4.437]	113.1 [4.453]	239.0 [9.409]	239.4 [9.425]	239.0 [9.409]	239.4 [9.425]	352.1 [13.862]	352.5 [13.878]
Tab Length	+Z dimension		mm [in]	361 [14.21]	366 [14.41]	361 [14.21]	366 [14.41]	361 [14.21]	366 [14.41]	361 [14.21]	366 [14.41]
EP _y	Ejection plate contact zone, +Y dimension from origin		mm [in]	-	100 [3.94]	-	100 [3.94]	-	213 [8.39]	-	326 [12.84]
DC_X1	Deployable contact zone with CSD, ±X face near +Y face		mm [in]	91.4 [3.598]	-	91.4 [3.598]	-	204.5 [8.051]	-	317.6 [12.504]	-
DC_X2	Deployable contact zone with CSD, ±X face near -Y face		mm [in]	-	20.3 [0.799]	-	20.3 [0.799]	-	20.3 [0.799]	-	20.3 [0.799]
DC_+Y	Deployable contact zone with CSD, +Y face (1)		mm [in]	43.85 [1.726]	-	107.0 [4.213]	-	107.0 [4.213]	-	163.55 [6.439]	-
DC_-Y	Deployable contact zone with CSD, -Y face (1)		mm [in]	31.2 [1.228]	-	94.3 [3.713]	-	94.3 [3.713]	-	150.9 [5.941]	-
F _{DS}	Force from deployment switches, summated, Z axis	When contacting CSD ejection plate	N	0	5.0	0	5.0	0	5.0	0	5.0
D _{DS}	Payload separation from ejection plate necessary to change deployment switch state, Z axis		mm [in]	1.3 [0.05]	12.7 [0.50]	1.3 [0.05]	12.7 [0.50]	1.3 [0.05]	12.7 [0.50]	1.3 [0.05]	12.7 [0.50]
F _{FD}	Friction force deployables impart on CSD walls during ejection	summated (all 4 sides)	N	0	2.0	0	2.0	0	2.0	0	4.0
F _{ND}	Normal force deployables impart on CSD walls during ejection	per bearing contact	N	0	9.0	0	9.0	0	9.0	0	9.0
TML	Total Mass Loss	Per ASTM E 595-77/84/90	%	0	1.0	0	1.0	0	1.0	0	1.0
CVCM	Collected Volatile Condensable Material	Per ASTM E 595-77/84/90	%	0	0.1	0	0.1	0	0.1	0	0.1
DP	CSD de-pressurization rate	During launch	psi/sec	0	0.5	0	0.5	0	0.5	0	0.5
D _x	Location of optional separation electrical connector, +X dimension		mm [in]	40.80 [1.606]	41.06 [1.616]	103.96 [4.093]	104.22 [4.103]	103.96 [4.093]	104.22 [4.103]	160.50 [6.319]	160.76 [6.329]

(1) Some contact zones are not present on the 3U. Refer to Figure 5 for locations.

COMMON REQUIREMENTS

1. Tabs shall be 100% continuous 7075-T7 aluminum alloy. Other aluminum alloys of equivalent or stronger yield strength may be substituted. Tabs shall also be Hard Anodized per MIL-A-8625, Type III, Class 1. All dimensions apply AFTER hard anodize. Note that Anodize thickness refers to the total thickness (i.e. 0.001 total thickness = 0.0005 penetration + 0.0005 build-up). Max surface roughness of Tabs = 0.8 μ m Ra.
2. Tabs shall run the entire length of the payload. No portion of the payload may extend beyond the tabs in the +Z or -Z directions.
3. Dimensions and tolerances in Figure 5 shall be maintained under all temperatures. Consider CTE warping of tabs if structure is not aluminum.
4. The structure comprising the -Z face (face that contacts CSD ejection plate) may be a uniform surface or consist of discrete contact points. The discrete contact points shall be located such that they envelope the payload's C.M. and the three deployment switches.
5. Deployment (inhibit) switches shall reside in specified zone on -Z face. Switches will activate upon contact with CSD ejection plate.
6. Safe/Arm plug, if necessary, shall reside in specified zone on +Z (preferred), +X, or -X face.
7. All non-constrained deployables shall be hinged near the +Z face to minimize snagging hazards during ejection. The deployables shall be tested with the CSD prior to flight.
8. -Z face of payload shall withstand a 400 N force imparted by CSD ejection plate during launch due to vibration.
9. If electrical grounding to the CSD is desired, the Separation Electrical Connector (In-Flight Disconnect) must be used. See Ref. 3.
10. The two tabs and the structure that contacts the CSD ejection plate on the -Z face are the only required features of the payload. The rest of the payload may be any shape that fits within the max dynamic envelope.
11. No debris shall be generated that will inhibit separation.
12. A fit check with a CSD shall be performed at the earliest possible time.

ELECTRICAL SCHEMATIC

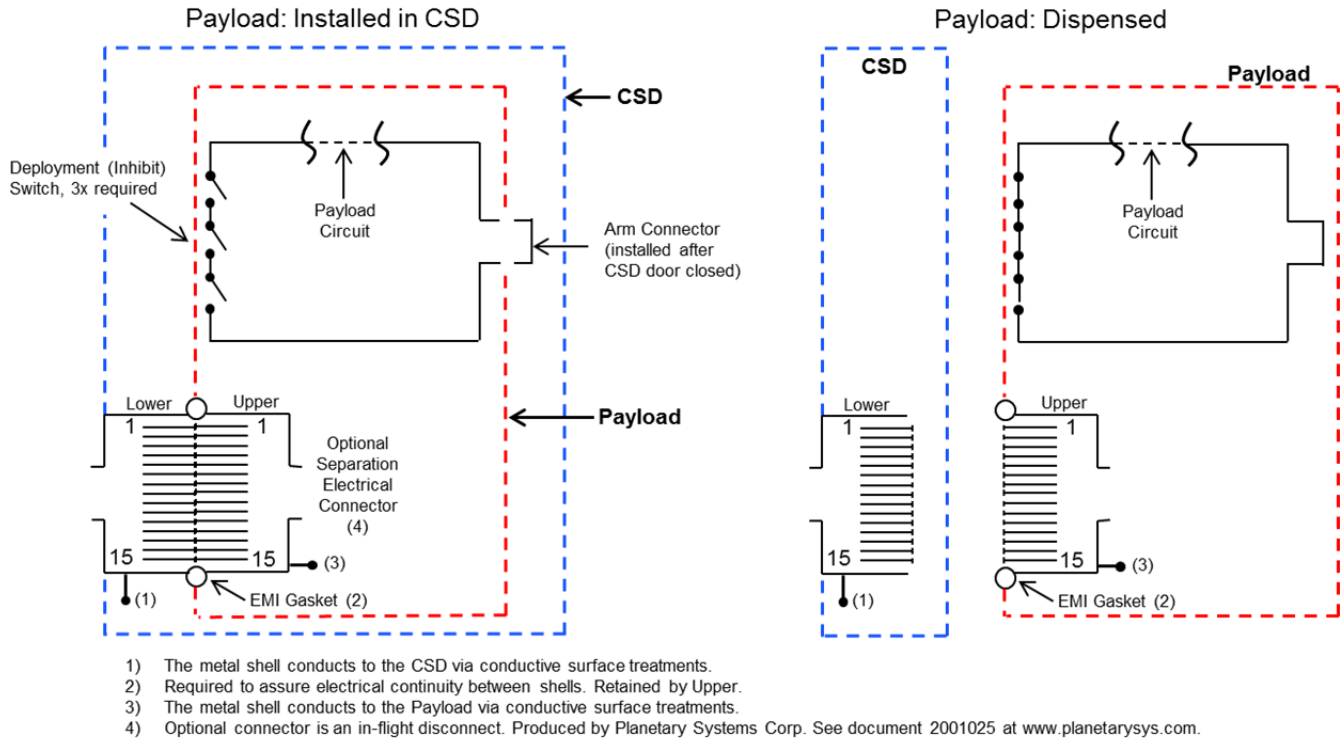


Figure 3: Electrical Schematic

DIMENSIONS

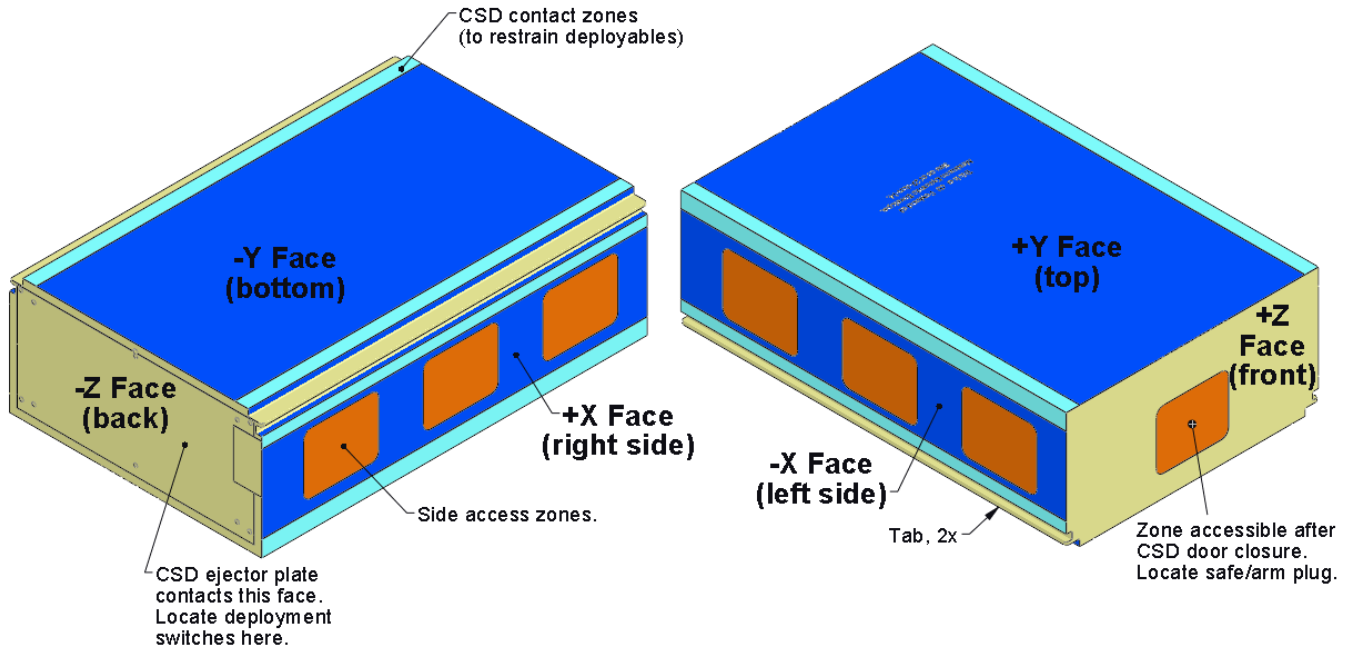


Figure 4: Payload Features (6U Shown)

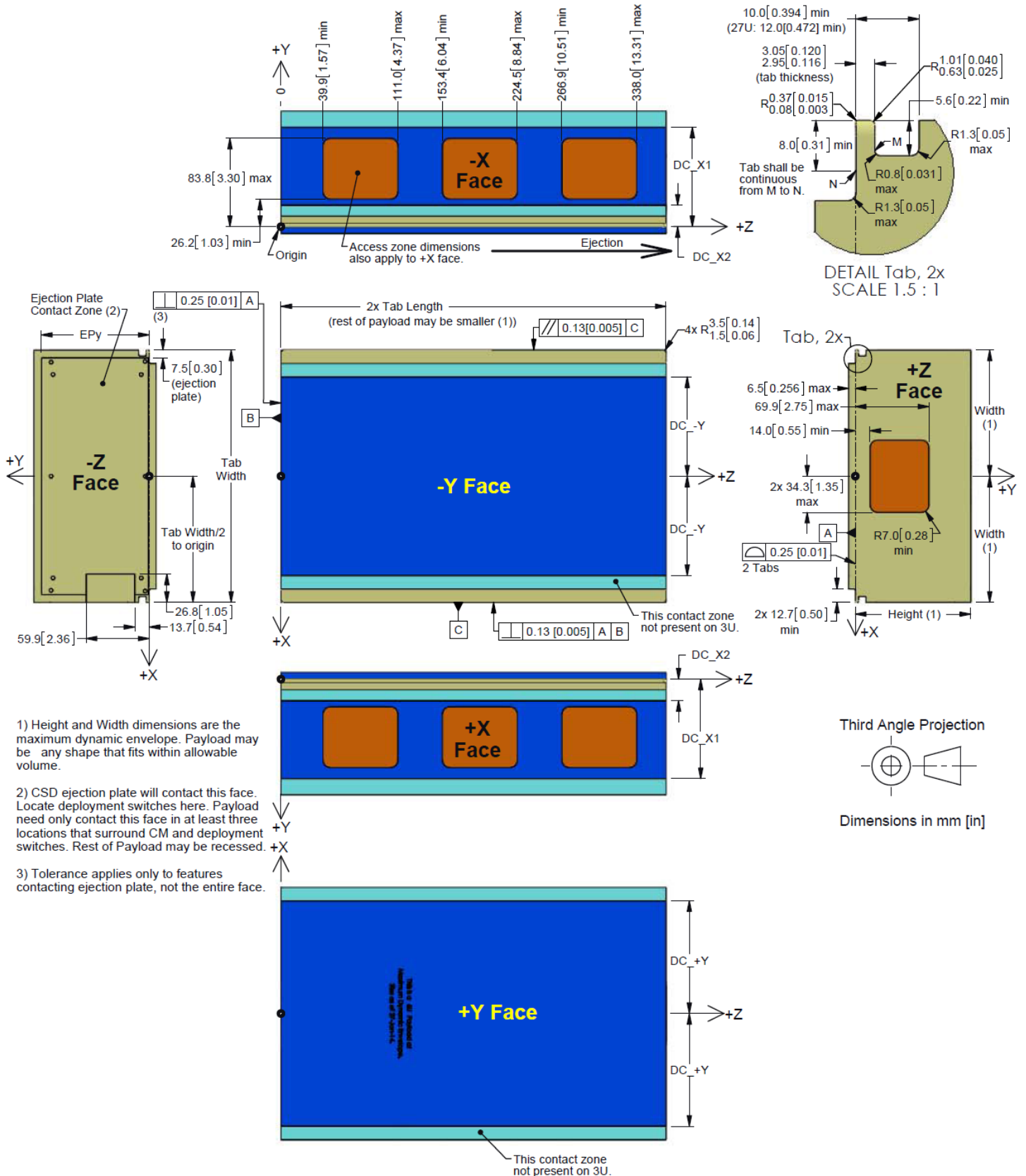


Figure 5: Payload Dimensions

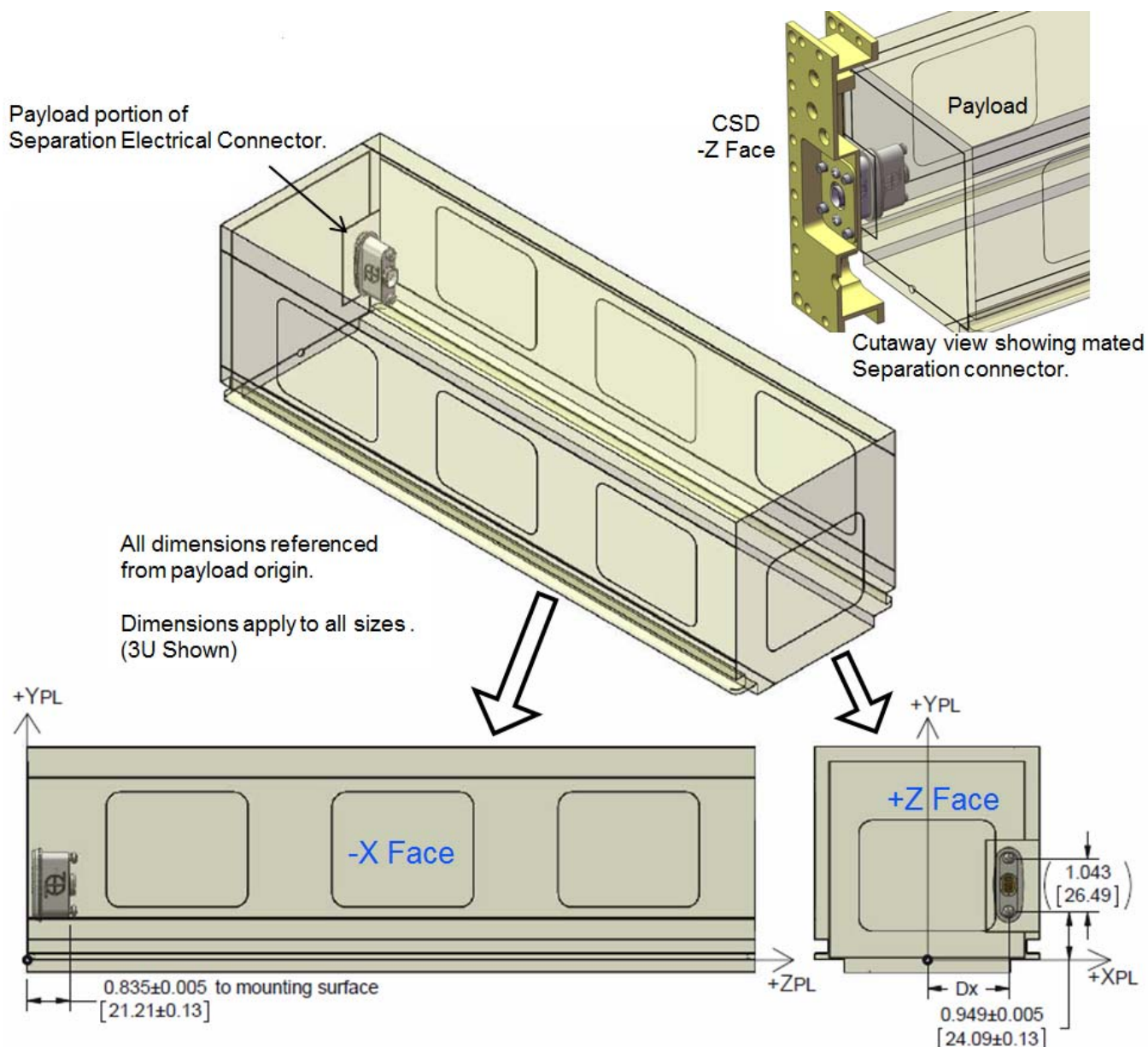
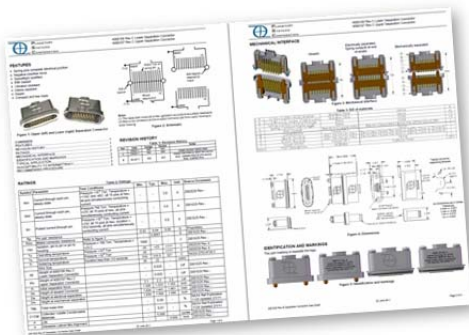


Figure 6: Location of Optional Separation Electrical Connector (In-Flight Disconnect)

For more information on the Separation Electrical Connector see PSC document 2001025 Separation Connector Data Sheet. Ref. 3. Also see section *Separation Electrical Connector Attachment*.



DISCRETE PAYLOADS

Multi-piece payloads are allowed provided they meet the following requirements.

- 1) Total length of all pieces: must comply with 'Tab Length' in Parameters Section.
- 2) Minimum allowable tab length of a single piece: 50mm [2.0 in].
- 3) Minimum tab gap between adjoining pieces (Z direction): 0.5mm [0.02 in].
- 4) Tab thickness of the extreme fore and aft pieces: equal to or greater than the adjoining piece.

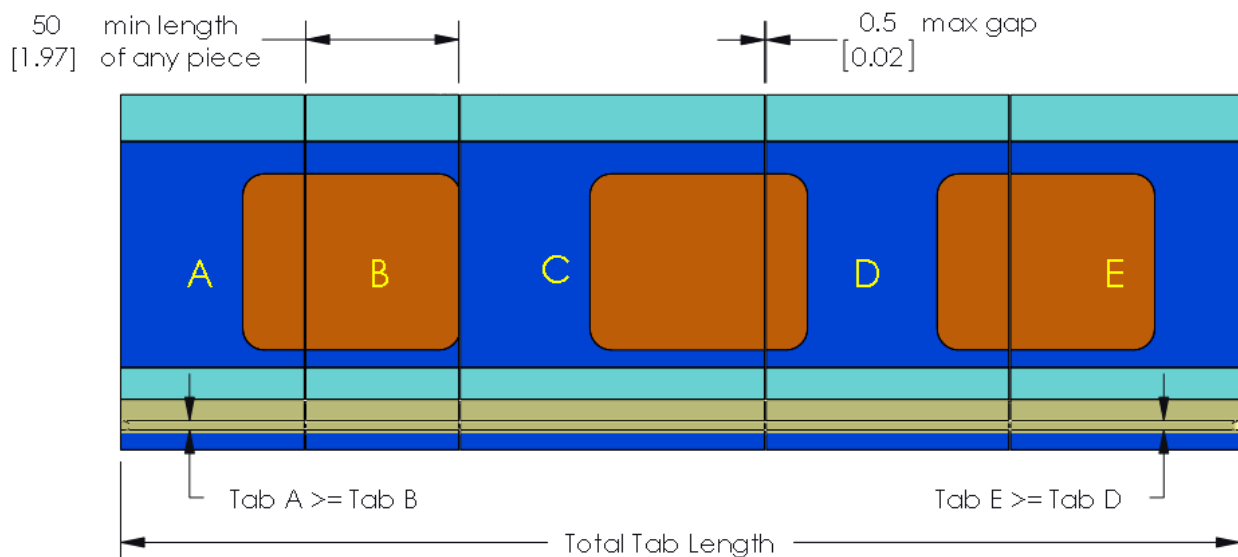


Figure 7: Generic Multi-Piece Payload (dimensions mm [in])

See Figure 24 and Figure 25 for examples of discrete payloads.

DESIGNS WITH TABS REMOVED

A payload can be designed with large tab gaps if necessary. This requires a CSD customization. Contact the CSD manufacturer if non-continuous tabs are desired.

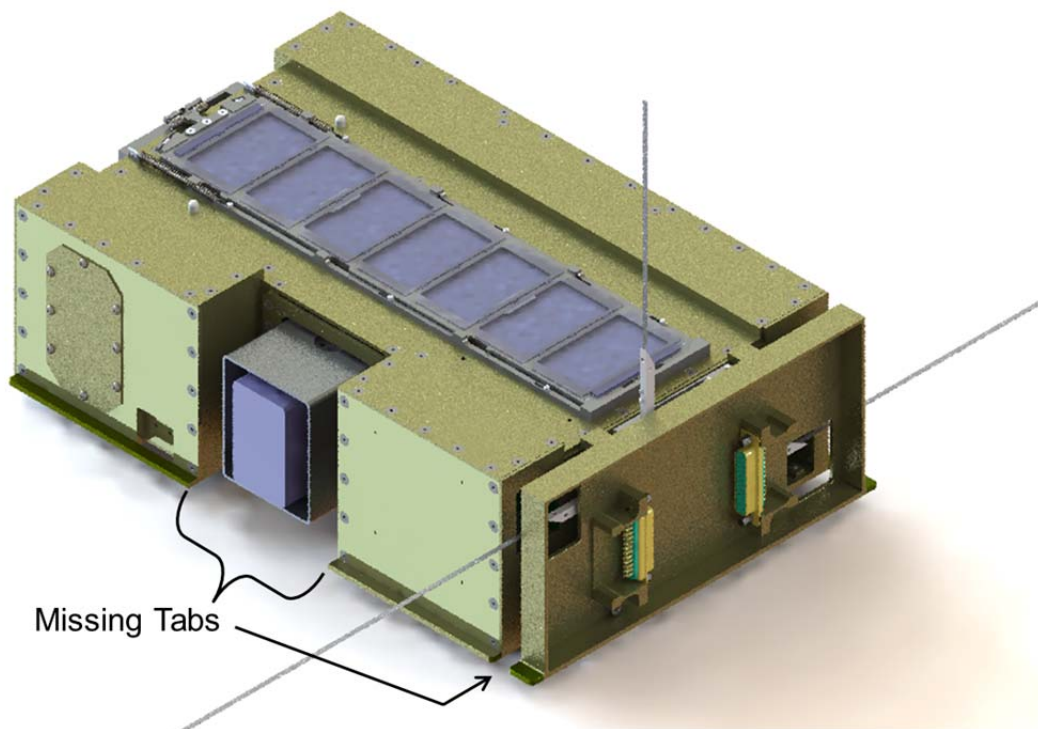


Figure 8: 6U Payload with Non-Continuous Tabs

BENEFIT OF TABS

Preloading the payload to the CSD by virtue of clamping the tabs creates a stiff invariant load path. This allows for accurate dynamic modeling to predict responses in anticipation of vibratory testing and space flight. Confidently predicting response is critical for aerospace structures and sensitive components. A payload that can move inside its dispenser is unmodelable and therefore the loading of sensitive components can not be predicted.

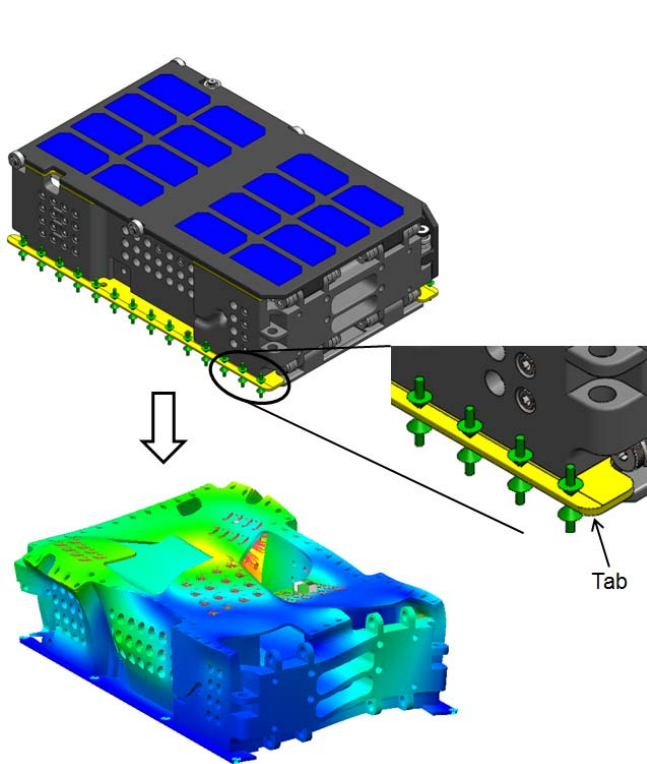
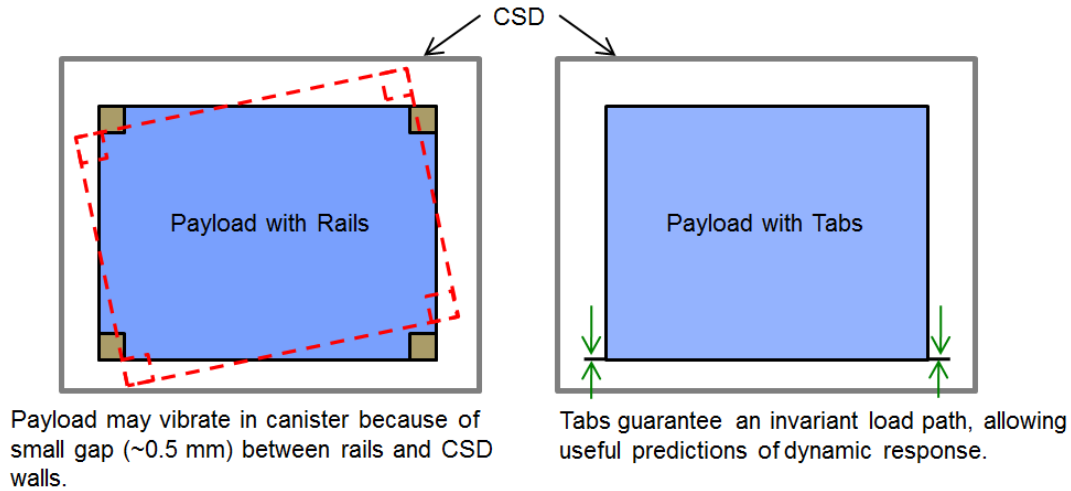


Figure 10: Prediction of 6U Dynamic Response

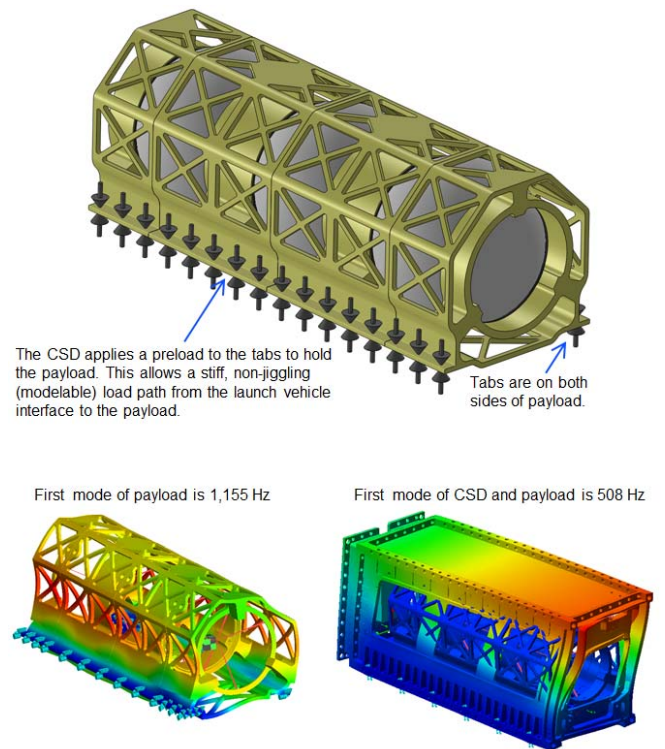
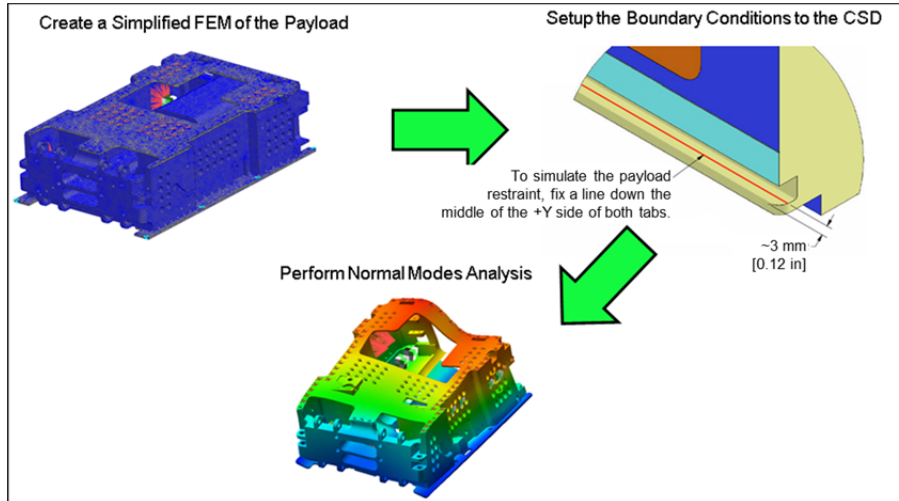


Figure 11: Prediction of 3U Dynamic Response

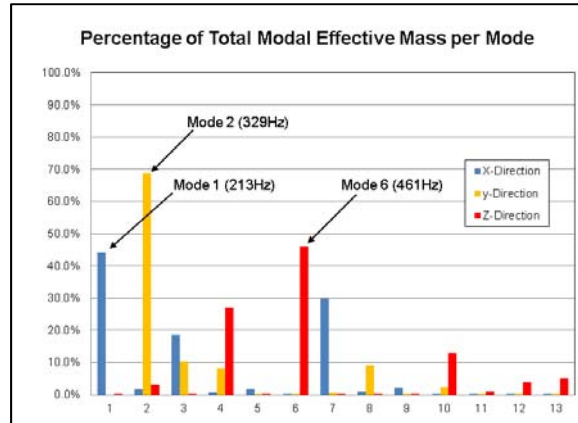
PREDICTING DESIGN LIMIT LOADS

The maximum structural loading typically results from the dynamic response during random vibration testing and/or shock testing. These loads are dependent on the mass, stiffness, and dampening properties unique to each payload. The method below provides a rudimentary means of predicting these loads.

- 1) Create a simplified model of the payload consisting of the primary structure and significant components for a Normal Modes Analysis from 20-2,000Hz.



- 2) Identify the dominant resonant frequencies and mode shapes for each orthogonal direction (X, Y, Z). These modes can be identified as having the highest percentage of Modal Effective Mass relative to all modes modeled within the frequency bandwidth stated above.



- 3) The response for a random vibration profile can be predicted by using the Miles Relation shown below:

$$Grms = \sqrt{0.5 * \pi * f_n * Q * ASD}$$

Grms [g] = 1σ acceleration response

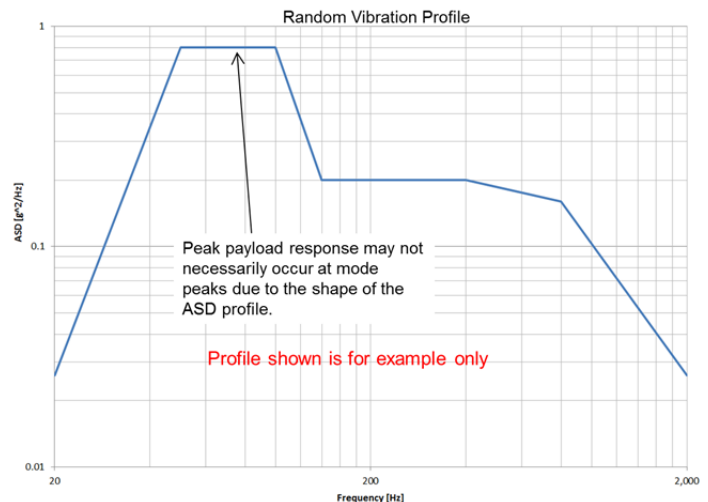
f_n [Hz] = natural frequency (frequency of selected mode)

Q [-] = $\frac{1}{2 * \zeta}$ = quality factor (use 10 as an estimate if unsure)

ζ [-] = critical dampening

ASD [g^2/Hz] = input acceleration spectral density at the desired frequency f_n

Assume the peak response is $3\sigma = 3 * Grms$



All payloads behave uniquely. The figure below shows two payload mockups of the same mass with very different responses. The mockup on the left has numerous discrete masses and bolted joints. There are many modes and the dampening is typical of many payloads. The mockup on the right consists of a few very stiff aluminum plates. There is one very dominate mode over a wide frequency range that results in significant loading.

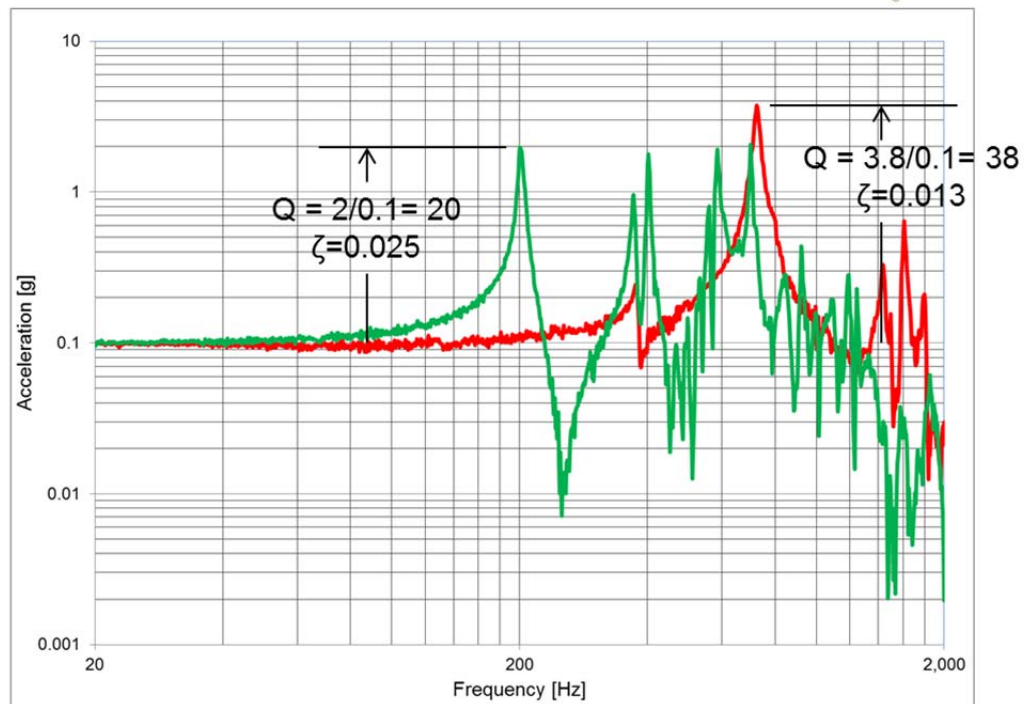
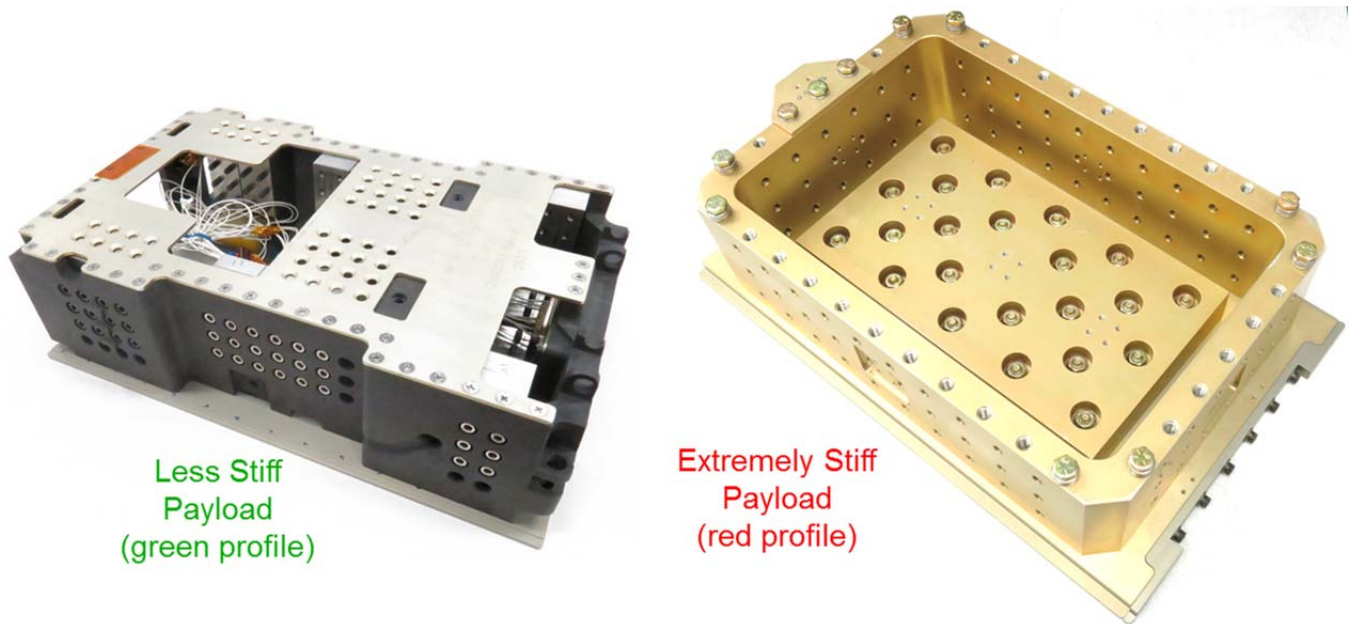


Figure 12: Comparison of Payload Responses

The response of the payload will significantly affect the loading on critical parts like reaction wheel bearings, complex mechanisms and optics. Ensuring a consistent load path from the launch vehicle to the payload (i.e. preloading) is the only way to accurately predict the loading from thermal, vibration and shock.

TAB MANUFACTURING

Designing and manufacturing tabs that meet the requirements of this document are critical for successful integration and deployment of a payload. As the interface to the CSD, the tabs shall be designed, dimensioned, manufactured, and inspected with care.

Production Drawings

The figure below shows an example production drawing of a plate with tabs. Some of the tolerances are tighter than this specification requires. Also, the tabs do not have to be on a discrete plate as shown. They can be discrete bolt-on features or machined into a more intricate structure.

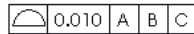
NOTES

1. Material: Al-Aly 7075-T7351 per AMS-QQ-A-250/12 or AMS 407B.
2. This is a Limited Dimension Drawing, governed by the following specifications.

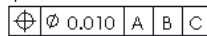
Basic: Features considered basic shall be defined in ANSI Y14.5M-1994.

Angles: All angles shall be considered basic unless otherwise noted.

Profile Tolerances: Unless otherwise noted, the profile tolerances shall be as follows (where A, B, and C are the primary, secondary, and tertiary datums respectively):



True Position Tolerance: Unless otherwise noted, the true position tolerance for features shall be as follows:



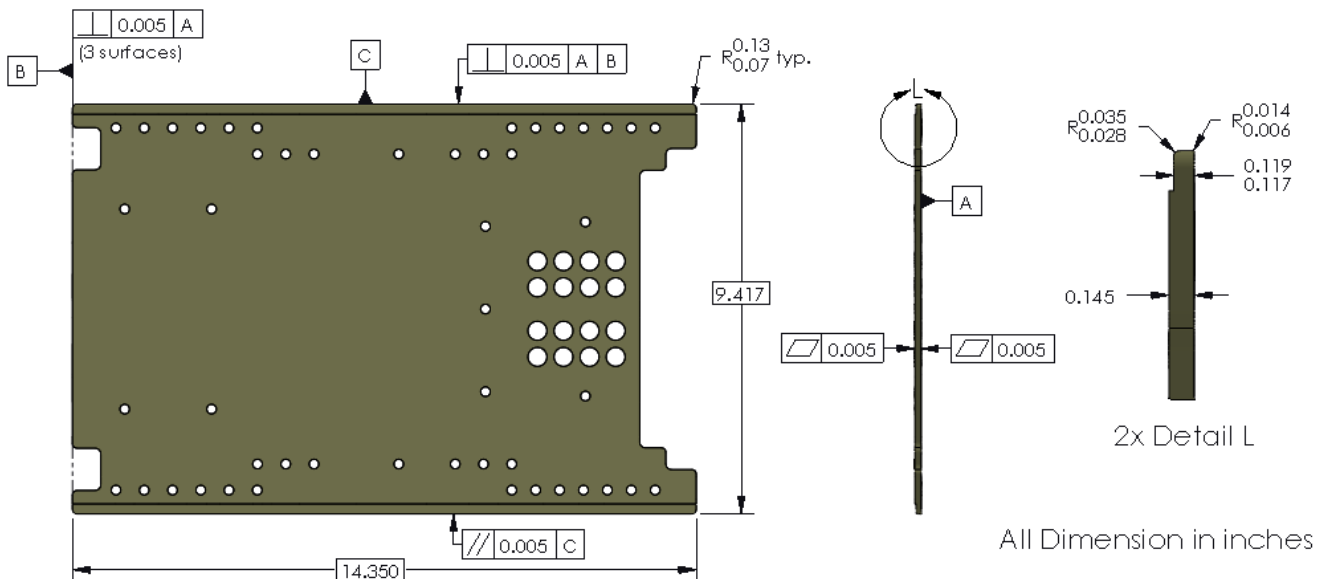
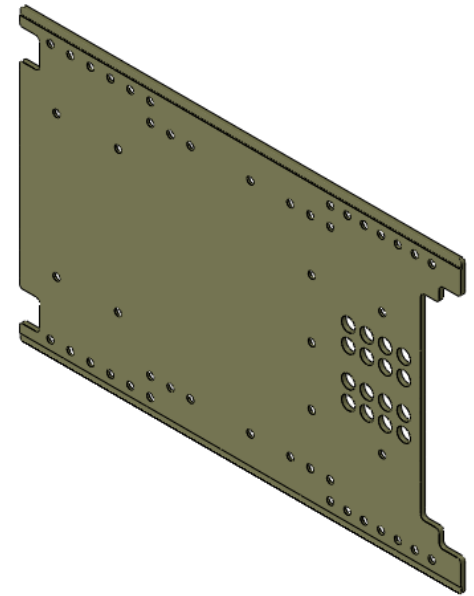
Surface roughness: Unless otherwise specified, MAX surface roughness shall be: $\sqrt{32}$

Internal radii: Internal machined corners shown as sharp edges may have R0.010 MAX.

External radii: External machined corners shown as sharp edges may have R0.010 MAX.

Holes: All holes shall have a diameter tolerance of ± 0.003 .

4. De-burr and break sharp edges.
5. All Dimensions apply after surface finish.
6. Surface Finish: Hard Anodize per MIL-A-8625, Type III, Class I, 0.0010 Thick (0.0005 penetration +0.0005 build-up = 0.001 total thickness)
No masking.
Do not contact precision tabs in Detail L during Plating.



All Dimension in inches

Inspection

Measure the tab thickness using a micrometer as follows. A digital caliper lacks the required accuracy.



Figure 14: Measuring Tab Thickness with Micrometer

- 1) Select a micrometer with an accuracy and resolution of 0.00005 inches (0.001 mm).
- 2) Ensure micrometer surfaces and tabs are clean.
- 3) Use a gauge block to verify micrometer accuracy and operator technique.
- 4) Mark increments at every inch along tab length.
- 5) Take minimum three measurements at each location to ensure repeatability.
- 6) Record and plot measurements.
- 7) All measurements shall be within tolerance. The figure below shows an example of tabs that are NOT acceptable.

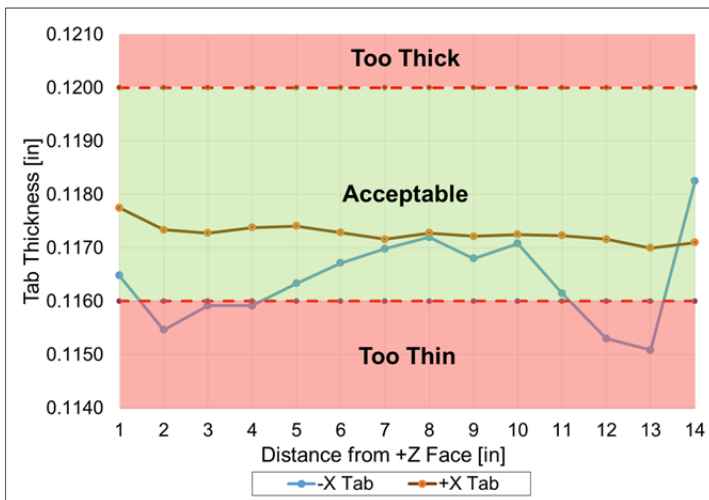


Figure 15: Tab Thickness Measurement

Also verify the following critical aspects of the tabs.

- 1) All edge fillets are in tolerance. See Detail L in Figure 13 for an example.
- 2) Hard anodize is continuous along entire tab surface (top, bottom and sides). Location defined as between M-N in Detail Tab in Figure 5.

After the payload structure is assembled the tabs shall remain flat per Figure 5. Place the payload on a verified flat surface (granite surface plates are ideal). A 0.010 inch thick feeler gage or gage pin shall not fit under any portion of the tab. See figure below.

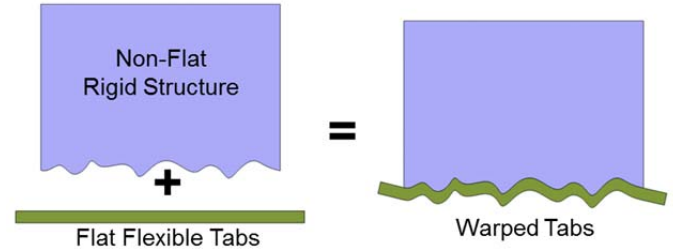


Figure 16: Example of Structure Warping Tabs



Figure 17: Verifying Assembled Flatness

CSD CONSTRAINED DEPLOYABLES

The payload may use the CSD to constrain deployables in designated areas as defined in the Parameters and Dimensions sections. At these designated contact zones the CSD interior surface shall be 1.3mm [0.05 in] from the maximum allowable dynamic envelope of the payload defined as 'Width' and 'Height'. Only the portion of the payload directly contacting the CSD Walls (bearing, etc.) may exceed the payload dynamic envelope.

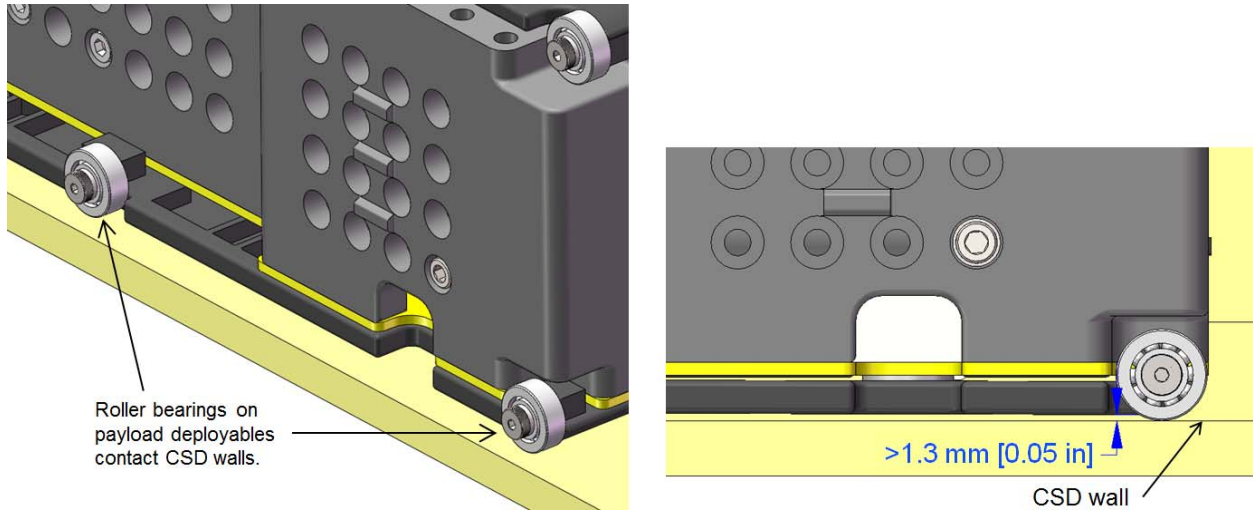


Figure 18: Deployable Contact with CSD

Deployables Design Notes:

- Ensure bearing spacing and panel stiffness are sufficient to prevent any portion of the panel from rubbing on the dispenser as the payload ejects.
- Deployables should have features to react shear loading at end opposite hinge. This prevents excessive loading on the hinge and deflection at the end of the deployable during launch.
- The deployable panels shall be sufficiently preloaded against the payload structure to minimize rattling during launch. This can be accomplished by incorporating a leaf spring, spring plunger, etc.
- Account for tolerance build-up in the deployable preload system. By necessity, the dispenser width will be greater than the tab width. During payload installation there will be up to 0.5mm [0.020 inches] of play relative to nominal in the +X or -X positioning of the payload. Therefore the +X or -X contact walls of the dispenser may be 0.8 to 1.8 mm [0.03 to 0.07 inches] from the payload's nominal max dynamic envelope.

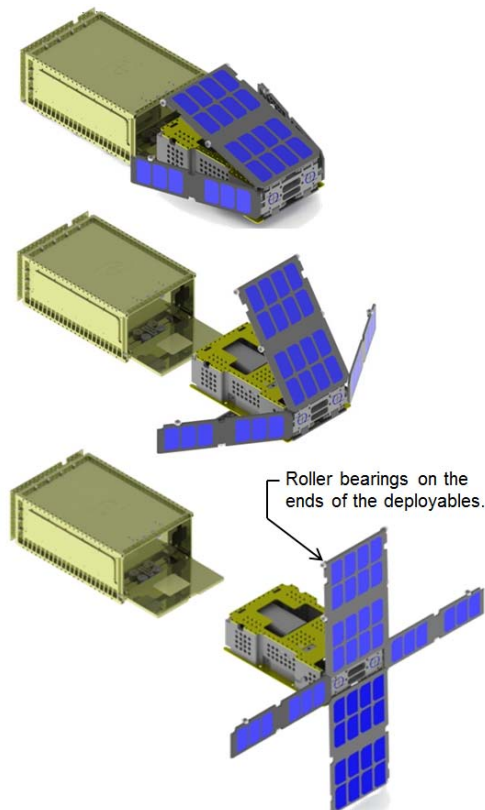


Figure 19: Payload Dispensing from CSD

PAYLOAD VOLUME

The allowable volume of the payloads is larger than existing CubeSats.

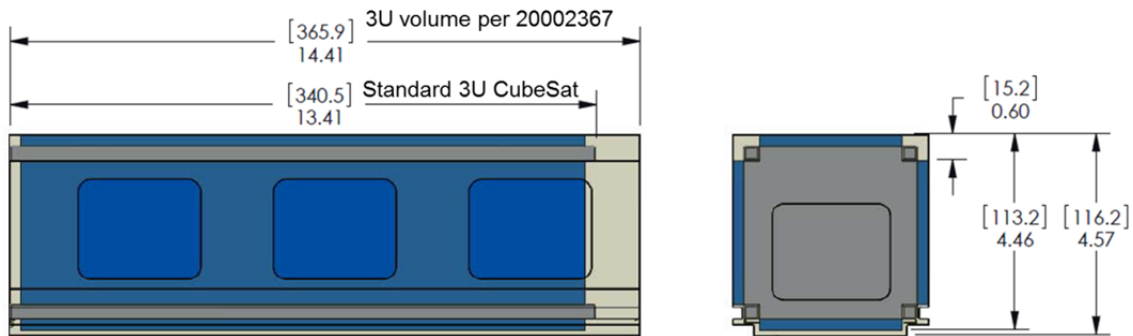


Figure 20: Comparison of 3U Payload Volumes. This specification allows 15% more payload volume.

Allowable Volume
PSC: 615 in³
Others: 564 in³

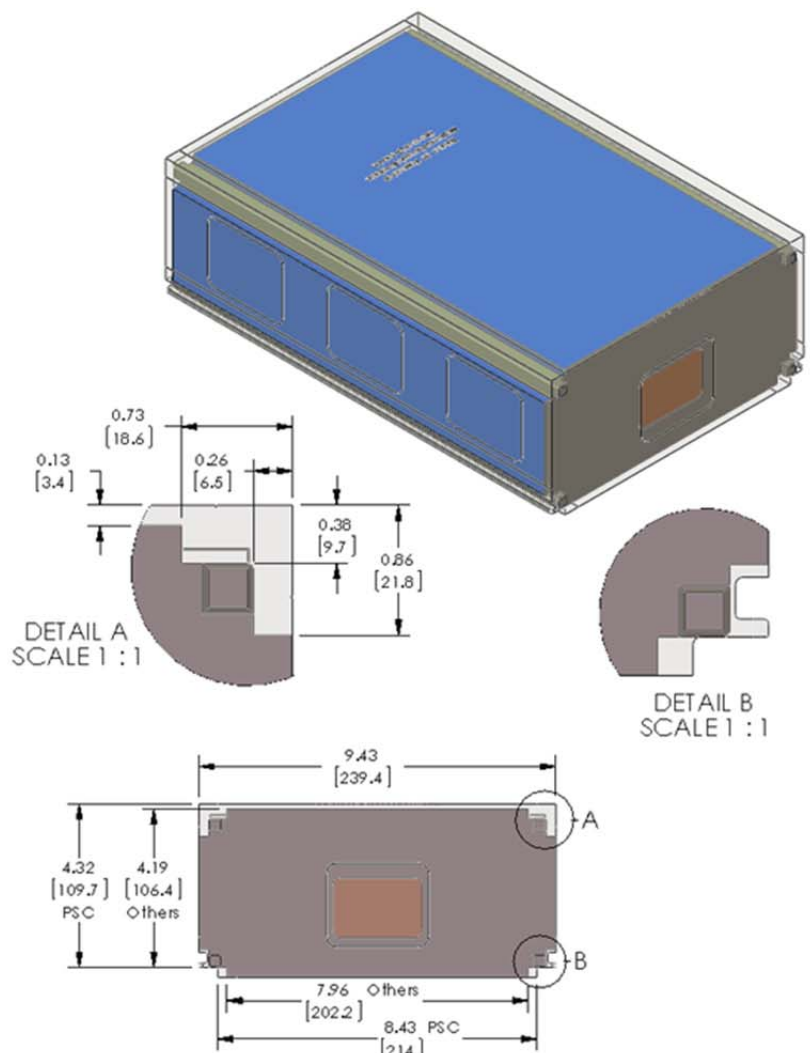
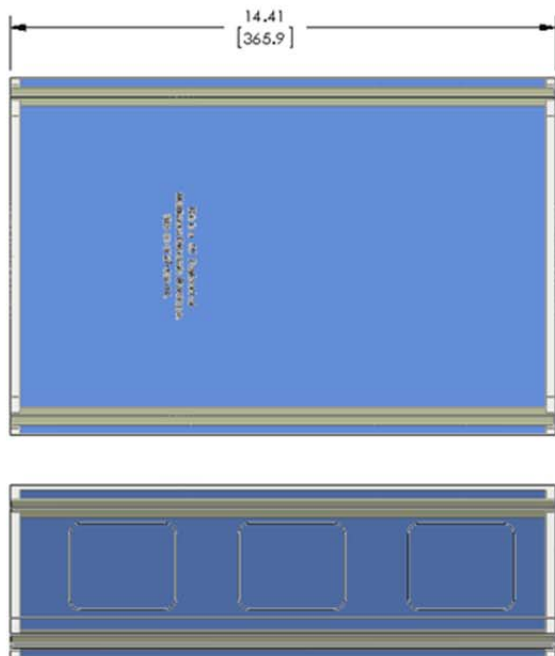


Figure 21: Comparison of 6U Payload Volumes. This specification allows 9% more payload volume.

TYPICAL APPLICATIONS

An existing CubeSat with 4 corner rails can easily comply with this specification by fastening on tabs.

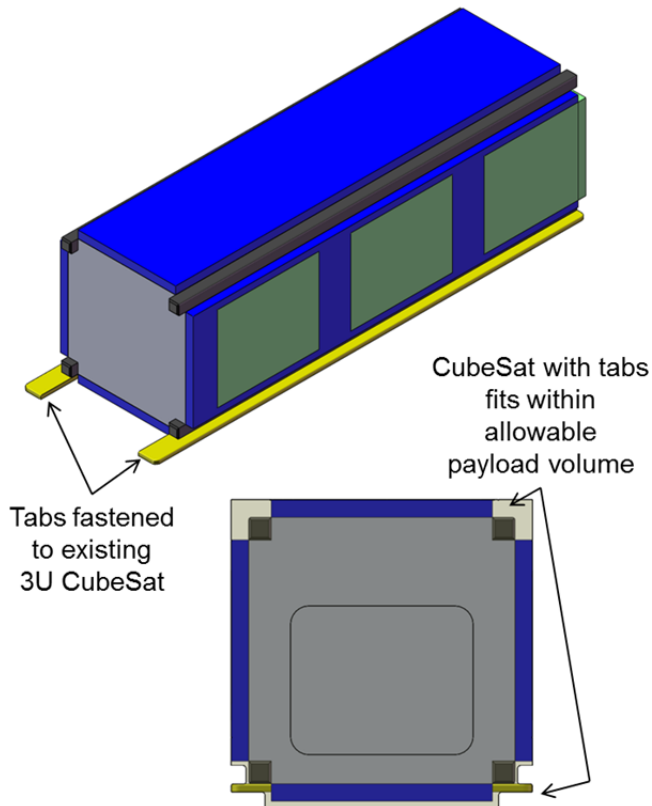


Figure 22: 3U CubeSat Tab Conversion

The payload need not occupy the entire volume as long as the tabs are present.

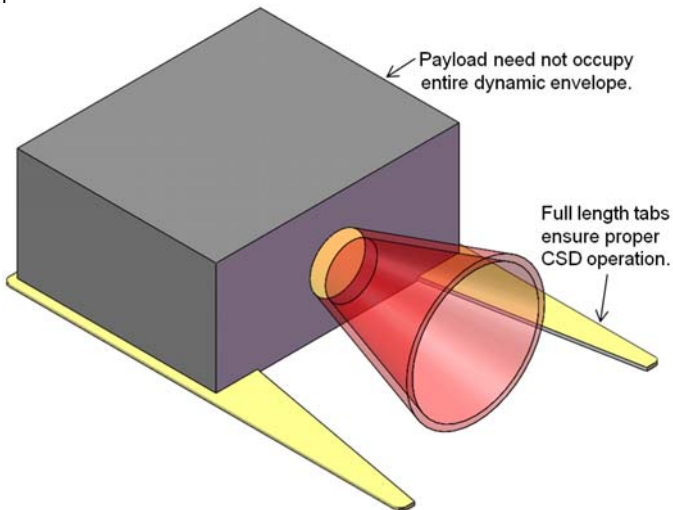


Figure 23: 6U Payload Example



Figure 24: POPACS, A Multi-Piece 3U Payload

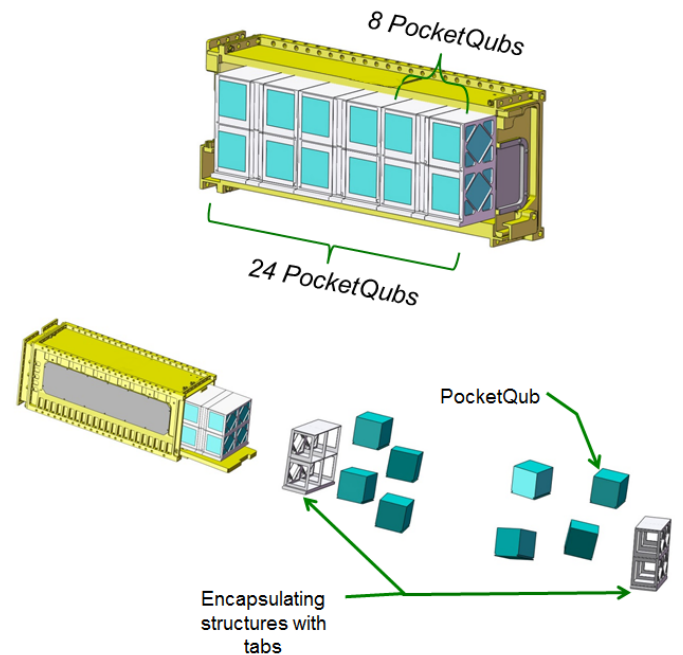


Figure 25: Encapsulating PocketQubs in a Tabbed Structure

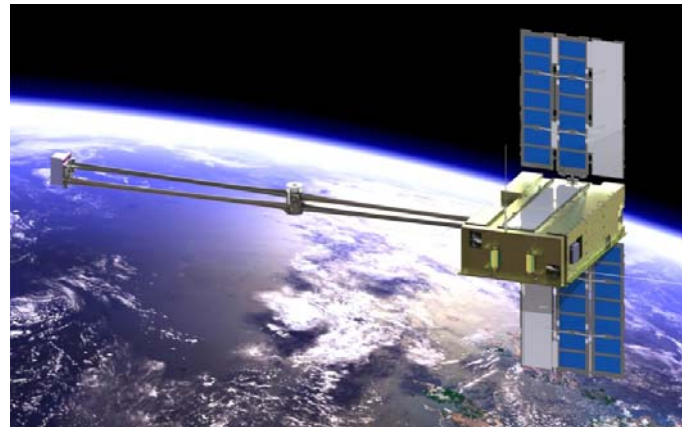


Figure 26: 6U Payload

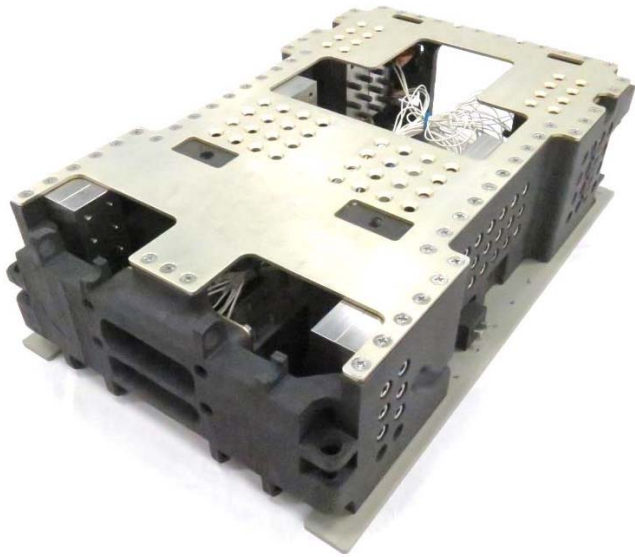


Figure 27: 3D Printed 6U Mockup Structure

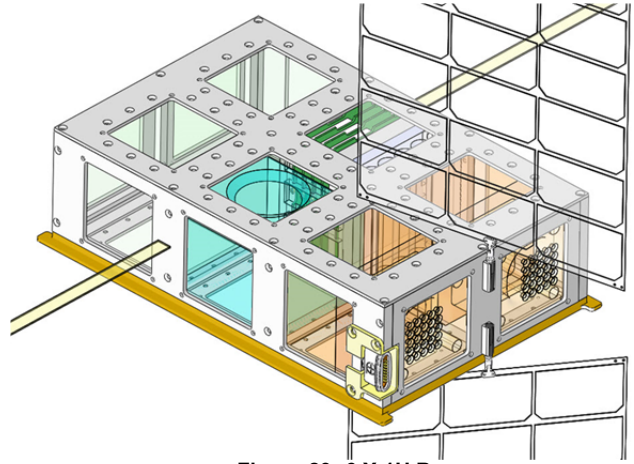


Figure 29: 6 X 1U Bus



Figure 28: Pumpkin Inc.'s 6U SUPERNOVA Bus

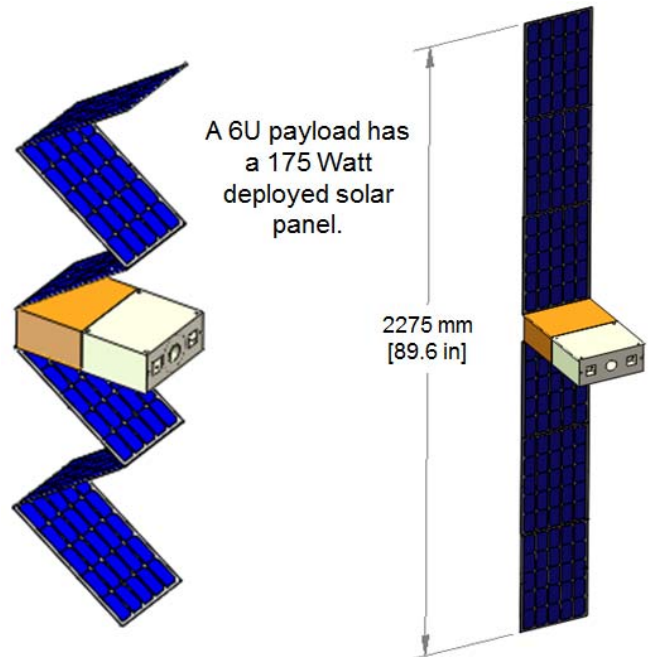


Figure 30: Solar Array Potential

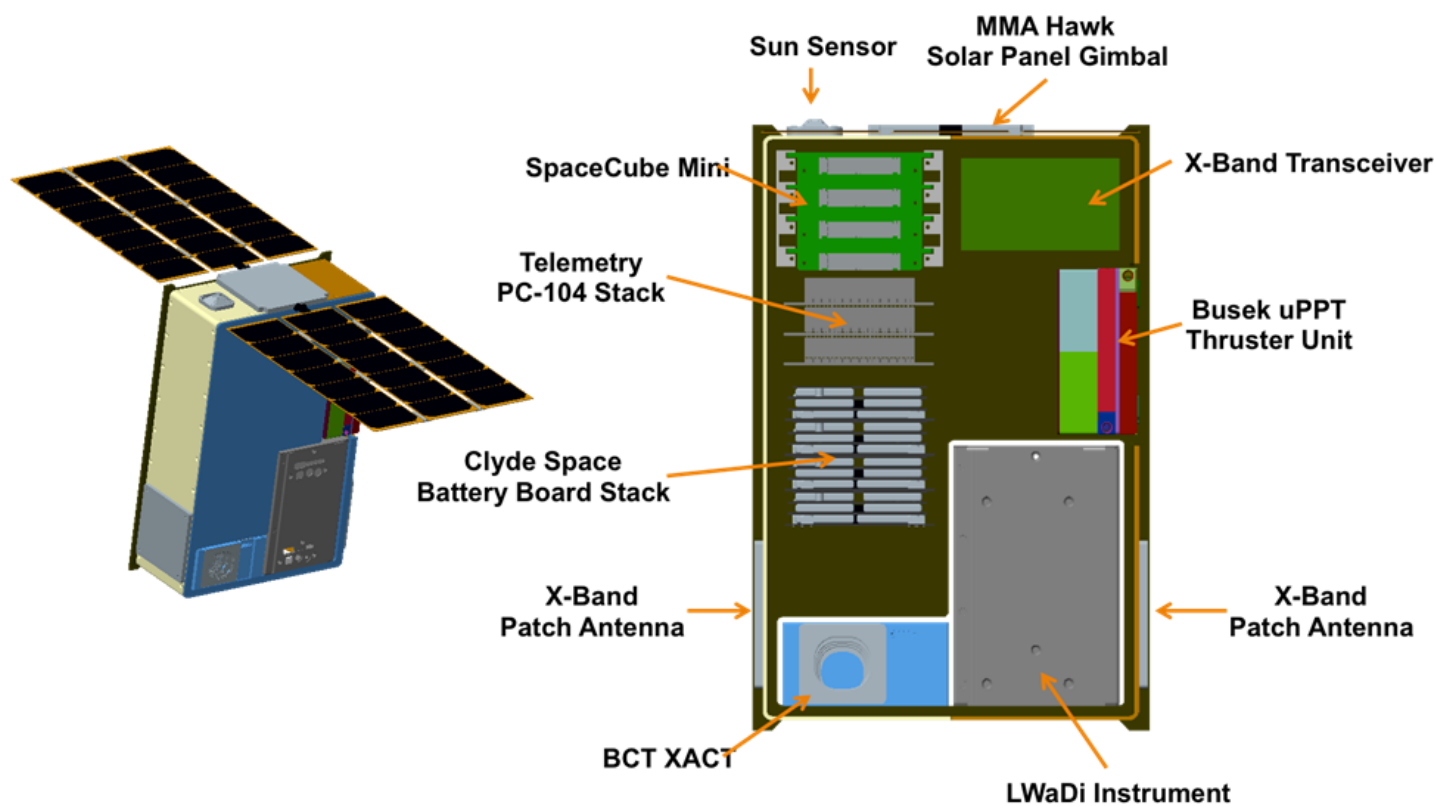


Figure 31: Lunar Water Distribution (LWADI), a 6U Interplanetary Spacecraft. Ref. 6.

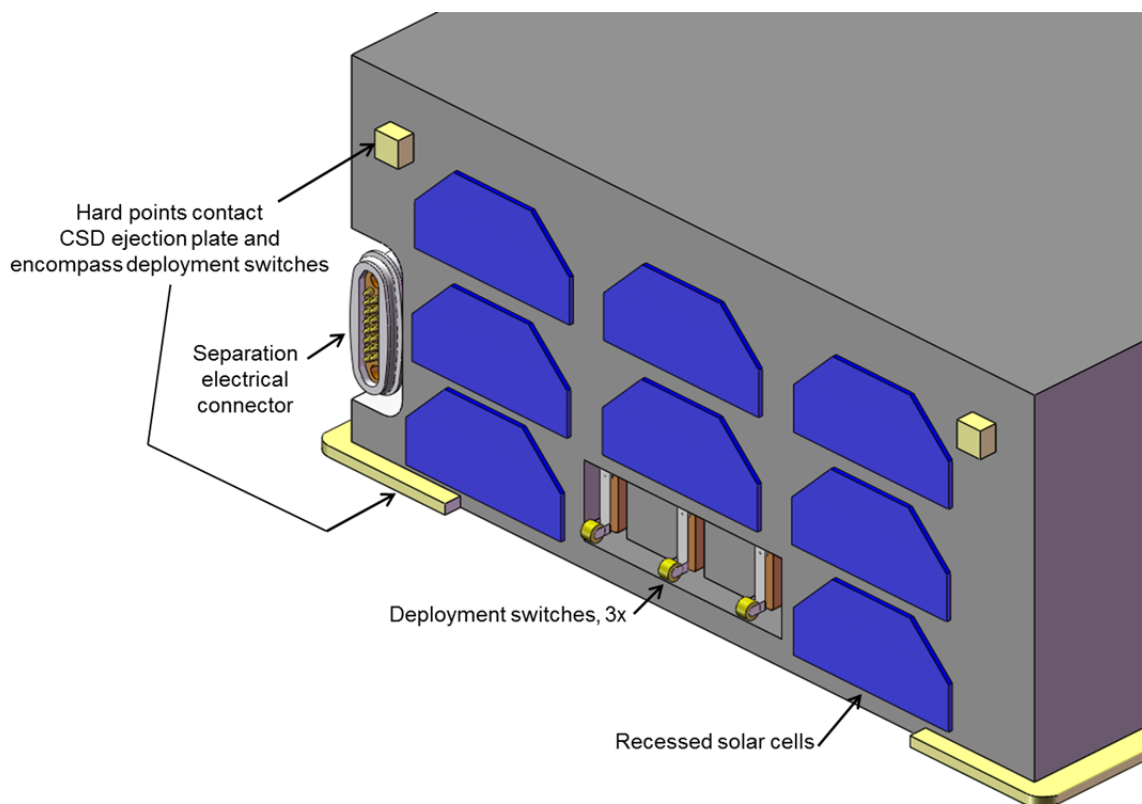


Figure 32: Example of -Z Face that Contacts Dispenser Ejection Plate

SEPARATION ELECTRICAL CONNECTOR ATTACHMENT

The figures below show a typical means of mounting the separation electrical connector. It only need be mounted via the flat face that contains the two #4 screws. Additional support around the side of the connector shell is unnecessary. An open cutout in the mounting bracket is beneficial as it allows the connector to be removed after the harness is wired.

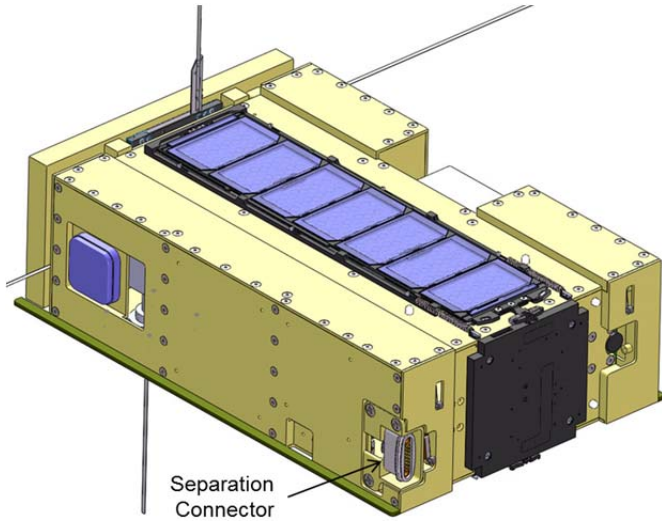


Figure 33: Separation Electrical Connector on Payload

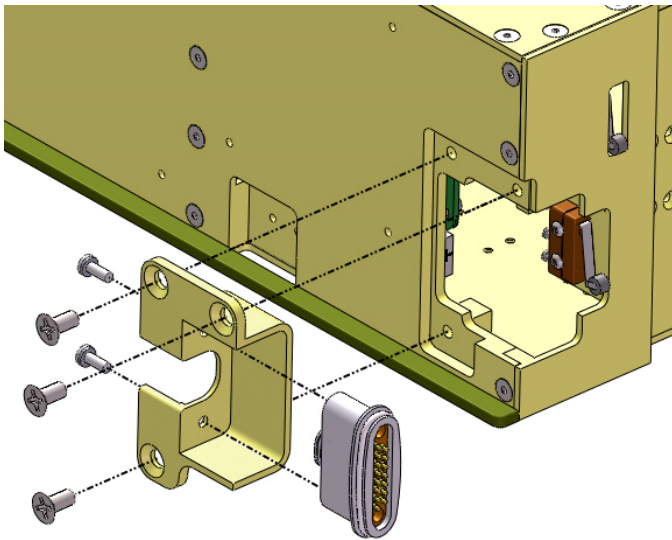
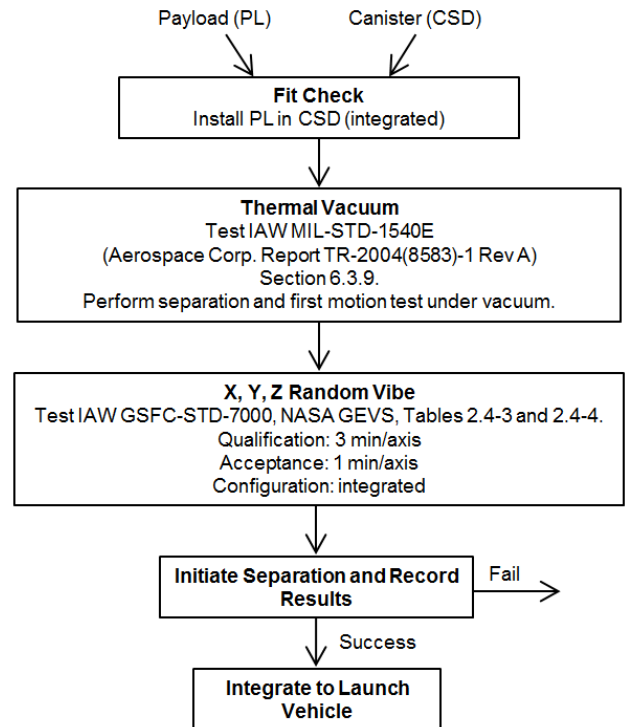


Figure 34: Separation Electrical Connector Mounting Example

RECOMMENDED TEST AND INTEGRATION

Test levels are for launch environment, not necessarily on-orbit.



TIPS AND CONSIDERATIONS

1. **Electrical Wiring:** Include the electrical harness in the CAD model. Ensure there are sufficient routing options, strain relief and clearances. Also, the harness can consume a significant portion of the allowable payload mass.
2. **Installation in CSD:** The payload may end up being installed vertically in the CSD (gravity in -Z). Add a removable handle on the +Z face to aide installation.
3. **CSD Ejection:** When possible, verify complete ejection of the payload from the CSD during testing.

CAD MODELS

Solid models of the payloads at their maximum dynamic envelope are available for download at www.planetarysys.com.

ADDITIONAL INFORMATION

Verify this is the latest revision of the specification by visiting www.planetarysys.com.

Please contact info@planetarysystemscorp.com with questions or comments. Feedback is welcome in order to realize the full potential of this technology.

REFERENCES

- 1 Hevner, Ryan; Holemans, Walter, "An Advanced Standard for CubeSats", Paper SSC11-II-3, 25th Annual AIAA/USU Conference on Small Satellites, Logan, UT, August 2011.
- 2 Holemans, Walter; Moore, Gilbert; Kang, Jin, "Counting Down to the Launch of POPACS", Paper SSC12-X-3, 26th Annual AIAA/USU Conference on Small Satellites, Logan, UT, August 2012.
- 3 Separation Connector Data Sheet, 2001025 Rev C, Planetary Systems Corp, Silver Spring, MD, July 2013.
- 4 CubeSat Design Specification, Rev 12, California Polytechnic State University, CA, Aug 2009.
- 5 Hevner, Ryan, "Lessons Learned Flight Validating an Innovative Canisterized Satellite Dispenser", Paper 978-1-4799-1622-1/14, 2014 IEEE Aerospace Conference, Big Sky, MT, January 2014.
- 6 Clark, Pamela, Holemans, Walter, Bradley, Wes, "Lunar Water Distribution (LWaDi)-- a 6U Lunar Orbiting spacecraft", 11th Annual Summer CubeSat Developers' Workshop, Logan, UT, 02-03 August 2014.

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REVISION HISTORY

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-	25-Jul-2012	RH	WH
A	06-Aug-2013	RH	WH
B	21-Jul-2014	RH	WH

Changes from previous revision:

Section(s)	Changes
Parameters	-Depth: changed to Height - Height: increased 3mm on 3U-12U . -FND: changed from 'per wall' to 'per bearing' EL: deleted
Common Requirements	Added Note 3 about thermal warping.
Dimensions	Fig. 5: Changed Datums. Changed edge fillet radaii on tabs.
Predicting Design Limit Loads	Added example payloads and their response profiles.
CSD Constrained Deployables	Added design note details.
Typical Applications	Added numerous figures.
Tips and Considerations	Deleted machining tolerance note.
Acknowledgements	Renamed from Authors. Removed PSC names. Added people.
Features & Benefits, Discrete Payloads, Designs with Tabs Removed, Tab Manufacturing, Payload Volume, References	Added.
Anticipated Improvements	Deleted.